DOCUMENT RESUME

ED 210 512	CE 030 784
TITLE	Energy Conservation. CORD Energy Technology Series.
INSTITUTION	Center for Occupational Research and Development, Inc., Waco, Tex.; Technical Education Research Centre-Southwest, Waco, Tex.
SPONS AGENCY	Office of Vocational and Adult Education (ED), Washington, D.C.
BUREAU NO	498AH80027
PUB DATE	Sep 81
CONTRACT	300-78-0551
NOTE	322p.; For related documents see CE 030 771-789 and ED 190 746-761.
AVAILABLE FROM	Center for Occupational Research and Development, 601 Lake Air Dr., Waco, TX 76710 ($2.50 per module; $17.50 for entire course).
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	Adult Education; Air Conditioning; Behavioral Objectives; Building Design; *Climate Control; Construction (Process); Course Descriptions; Courses; Efficiency; Electric Motors; *Energy; *Energy Conservation; Fuel Consumption; Glossaries; Heating; Laboratory Experiments; Learning Activities; Learning Modules; Lighting; Postsecondary Education; *Power Technology; *Technical Education; Two Year Colleges
IDENTIFIERS	*Energy Consumption

ABSTRACT

This course in energy conservation is one of 16 courses in the Energy Conservation-and-Use Technology curriculum. Intended for use in two-year postsecondary technical institutions to prepare technicians for employment, the courses are also useful in industry for updating employees in company-sponsored training programs. Comprised of seven modules, the course is designed to give the student technical knowledge and specific skills required to perform conservation measures relative to the most common energy uses. The student learns and utilizes the basic principles of energy conservation and efficiency. Written by a technical expert and approved by industry representatives, each module contains the following elements: introduction, prerequisites, objectives, subject matter, exercises, laboratory materials, laboratory procedures (experiment section for hands-on portion), data tables (included in most basic courses to help students learn to collect or organize data), references, and glossary. Module titles are Energy Conservation--An Introduction, Conservation Principles and Efficiency Measurements (CPEM)--Space Heating, CPEM--Space Cooling, CPEM--Hot Water and Steam Supply Systems, CPEM--Illumination, CPEM--Electric Motors, and CPEM--Building Construction. (YLB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED210512

ENERGY
CONSERVATION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
601 LAKE AIR DRIVE
WACO, TEXAS 76710

CE030784

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.

- Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

D.M. Hull

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SEPT. '81

PREFACE

ABOUT ENERGY TECHNOLOGY MODULES

The modules were developed by CORD for use in two-year postsecondary technical institutions to prepare technicians for employment and are useful in industry for updating employees in company-sponsored training programs. The principles, techniques, and skills taught in the modules, based on tasks that energy technicians perform, were obtained from a nationwide advisory committee of employers of energy technicians. Each module was written by a technician expert and approved by representatives from industry.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify, and define, rather than words with many interpretations such as know, understand, learn, and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Laboratory Materials, which identify the equipment required to complete the laboratory procedure.

Laboratory Procedures, which is the experiment section, or "hands-on" portion, of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

References, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of prestated objectives.

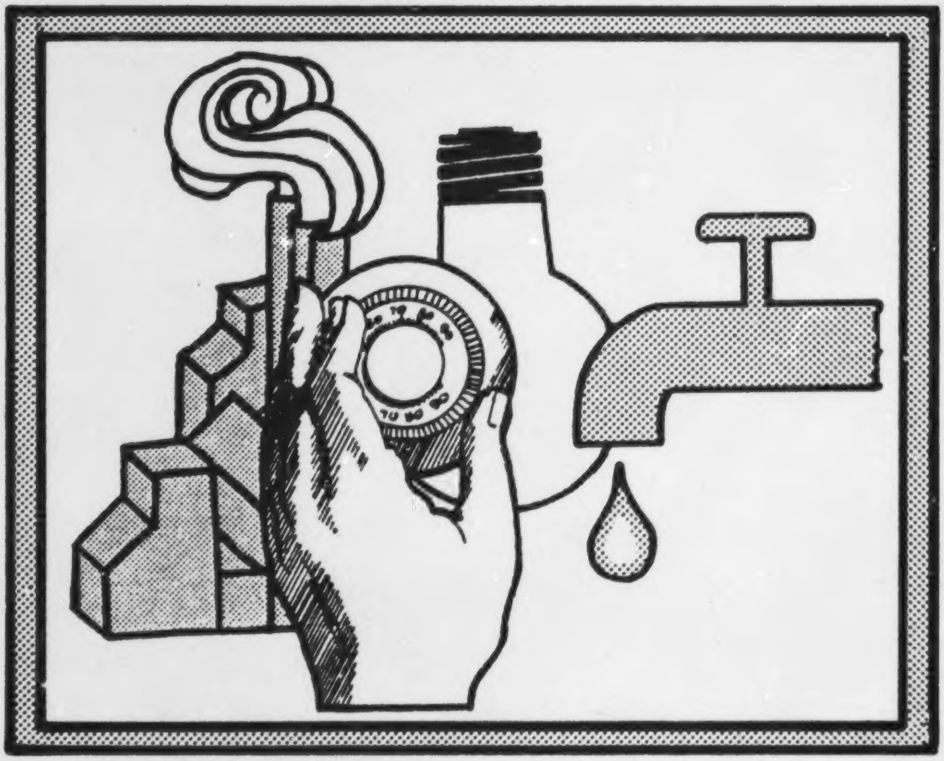
CONTENTS

MODULE EC-01 Energy Conservation – An Introduction
MODULE EC-02 Conservation Principles and Efficiency Measurements – Space Heating
MODULE EC-03 Conservation Principles and Efficiency Measurements – Space Cooling
MODULE EC-04 Conservation Principles and Efficiency Measurements – Hot Water and Steam Supply Systems
MODULE EC-05 Conservation Principles and Efficiency Measurements – Illumination
MODULE EC-06 Conservation Principles and Efficiency Measurements – Electric Motors
MODULE EC-07 Conservation Principles and Efficiency Measurements – Building Construction

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-01

ENERGY CONSERVATION - AN INTRODUCTION

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

"Energy Conservation – An Introduction" is a module that is fundamental in nature, designed to give the student a review of information presented in previous courses. This module discusses availability and utilization of energy sources and describes utilization of energy in the economy of the United States. It also reviews basic principles for conservation of energy in energy-using equipment and in building construction and use. The fundamentals discussed in this module are prerequisite to required task decisions and skills required in subsequent modules.

PREREQUISITES

The student should have completed one year of high school algebra, Unified Technical Concepts I, II, and III, Fundamentals of Energy Technology, and Energy Production Systems.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe energy flow in the U.S. economy and include the nature of primary sources, energy-conversion devices, and end uses and losses.
2. Calculate doubling time for use of a resource, given the rate of increased use.
3. State at least three advantages of energy conservation.

4. Describe the long term historical use of petroleum in the past, present, and future.
5. Discuss the costs of natural gas, fuel oil, and coal, as well as the expected price trends for each.
6. Given information about fuel usage, such as the given period and the average climate at a given location, calculate how much fuel may be expected to be used in a future period.
7. Describe the historical growth pattern of energy usage in the U.S.
8. Discuss methods for energy conservation in the following areas:
   a. Energy-using equipment.
   b. Building construction and use.
   c. Automotive transportation.
9. Estimate expected fuel usage for a specific building, based on observations made by the student.

AVAILABILITY OF ENERGY SUPPLIES

The discussion of energy conservation begins by considering the flow of energy in the U.S. economy. Figure 1 illustrates energy flow, showing major sources, types of energy-conversion facilities, and end uses. The thickness of the bars is approximately equal to the relative amount of energy used in each application. The most important sources of energy are presented quantitatively in Table 1.

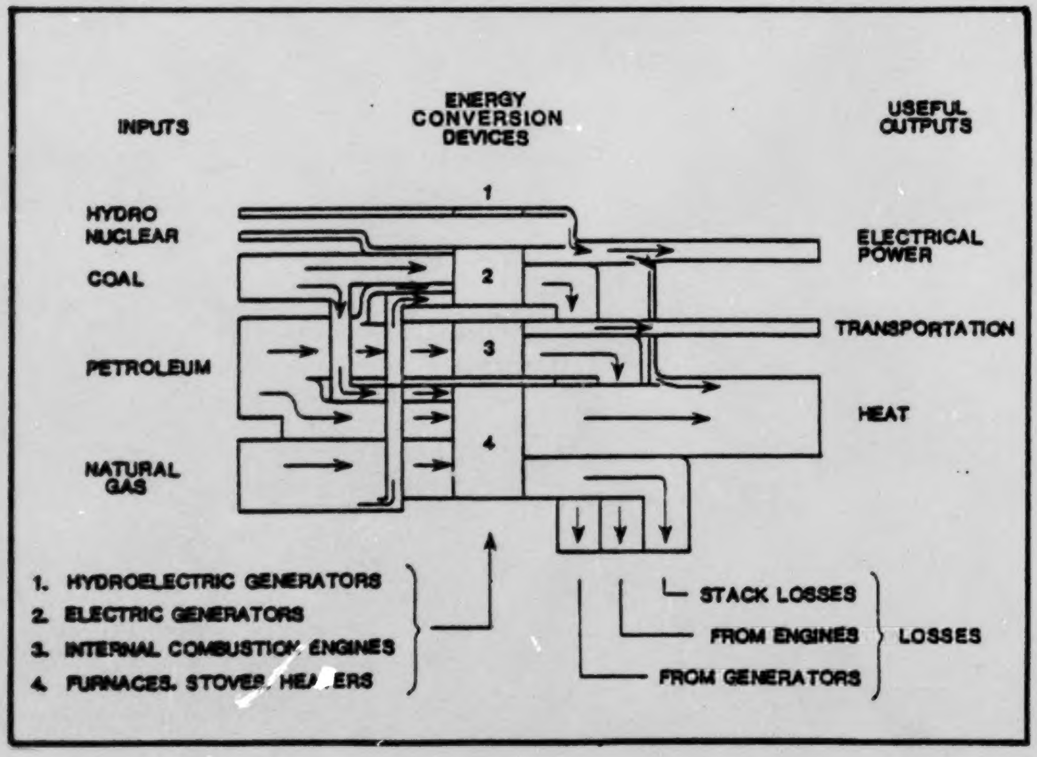

INPUTS
ENERGY CONVERSION DEVICES
USEFUL OUTPUTS
HYDRO
NUCLEAR
COAL
PETROLEUM
NATURAL GAS
1
2
3
4
ELECTRICAL POWER
TRANSPORTATION
HEAT
1. HYDROELECTRIC GENERATORS
2. ELECTRIC GENERATORS
3. INTERNAL COMBUSTION ENGINES
4. FURNACES, STOVES, HEATERS
STACK LOSSES
FROM ENGINES
FROM GENERATORS
LOSSES

Figure 1. Flow of Energy in the United States.

TABLE 1. PRIMARY SOURCES OF ENERGY IN THE UNITED STATES.

Source	Percentage
Petroleum	45%
Natural Gas	30%
Coal	18%
Hydroelectricity	4%
Nuclear Energy	3%

Petroleum accounts for almost half of the energy supply; it is used mainly for internal combustion engines and for heating homes, offices, and factories. Natural gas also accounts for a major fraction of energy utilization; its major use is for direct heating. Coal, the next largest source, is used mainly for generating electricity. Hydroelectricity is an important source of electrical power in certain parts of the United States, notably the Pacific Northwest. However, hydroelectric plants must depend on the force of water dropping from a substantial height — which limits their usefulness. Applications of nuclear energy are expected to increase, yet the outlook (for nuclear energy) is presently clouded by opposition of many people because of social and ecological factors. Nuclear energy is used for electrical generation.

Other sources of energy — solar, geothermal, wind, and tidal energy — account for only a very small fraction of the total energy used. Use of these sources may increase, but the rate of increase will depend on advances in research and development.

Figure 1 and Table 1 do not include biological energy sources, for example, food which is consumed by human beings or animals.

The types of energy conversion devices that convert energy from primary sources into useful heat and work include generators, engines, furnaces, stoves, and heaters (Figure 1). Thus, electrical generation, either by thermal generation or hydroelectric generation, draws upon all primary energy sources. Transportation is fueled almost exclusively by petroleum; and heating applications rely on natural gas, petroleum, and coal.

There are losses associated with each conversion. In thermal electric generation, most of the energy is wasted, and perhaps only about 25% is converted into electrical energy. Internal combustions are also inefficient, with, again, about 25% of the available energy being converted into useful mechanical work. The loss associated with heaters and furnaces is mainly stack loss, that is, the heat energy that goes up the smokestack.

Transmission accounts for a smaller percentage of energy loss. About 3% of electrical energy produced at a generating plant is lost in transmission to the end user. Even less is lost in transmission of fuels. For example, virtually 100% of the oil put into one end of a pipeline will emerge from the other end.

These losses (illustrated by the bars which emerge from the bottom of Figure 1) represent energy that is not available for producing heat or work. Since energy losses consume a large fraction of the total energy input, an important part of energy conservation involves reducing these losses.

Figure 2 shows various stages of energy losses for natural gas and electrical heating systems, beginning with the primary source (fuel) and ending with delivery of heat to a home (the end user). Natural gas heating involves virtually no energy loss in a transcontinental pipeline and a flow percent loss in a local distribution system. The

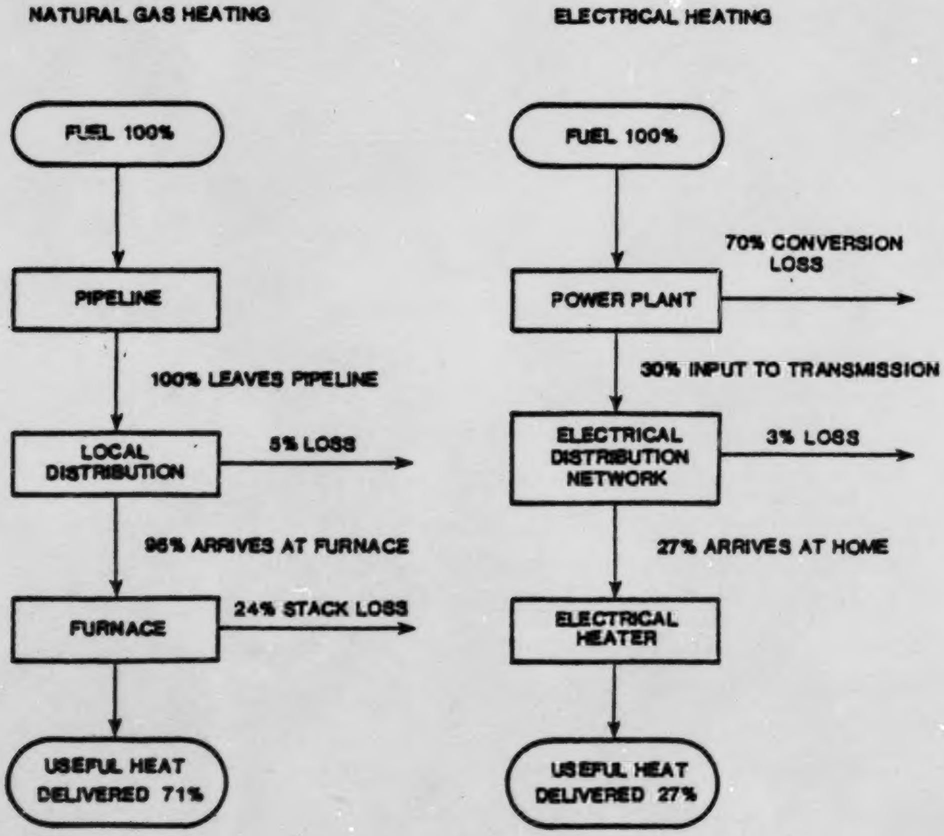

NATURAL GAS HEATING
FUEL 100%
PIPELINE
100% LEAVES PIPELINE
LOCAL DISTRIBUTION
5% LOSS
95% ARRIVES AT FURNACE
FURNACE
24% STACK LOSS
USEFUL HEAT DELIVERED 71%
ELECTRICAL HEATING
FUEL 100%
70% CONVERSION LOSS
POWER PLANT
30% INPUT TO TRANSMISSION
ELECTRICAL DISTRIBUTION NETWORK
3% LOSS
27% ARRIVES AT HOME
ELECTRICAL HEATER
USEFUL HEAT DELIVERED 27%

Figure 2. Overall Efficiency of Heating Systems.

furnace loses approximately 24% of the heat up the chimney. Thus, approximately 71% of the total energy contained in the fuel is delivered to the home as useful heat. In an electrical heating system, the heater itself is essentially 100% efficient, that is, all energy delivered to the heater is converted to useful heat. The major loss occurs during the generation process. Approximately 70% of the energy contained in the primary fuel is lost during this process; and 3% more is lost in transmission. Thus, of the original energy content of the fuel, only about 27% appears as useful heat in the home.

The right side of Figure 1 shows the main end uses of energy: electrical power, transportation, and heat.

The uses of electrical power include lighting, air conditioning, residential appliances, and powering of industrial machinery. Transportation is mainly powered by internal combustion engines which predominantly use petroleum. Transportation involves automobiles, motorcycles, buses, airplanes, boats, and farm machinery. Heating applications include heating of homes, offices, factories, schools, and so forth. This latter category also includes cooking, water heating, and industrial process heating.

In addition, there are some non-energy uses of petroleum which are not included in Figure 1. These uses include production of petrochemicals such as plastics and asphalt.

Table 2 presents an approximate breakdown of the end uses of energy. The breakdown in each category includes the total amount of energy directed toward each end use. Thus, the 25% devoted to transportation includes the amount delivered as useful work plus the amount lost in producing this useful work.

TABLE 2. END USES OF ENERGY.

Electrical Power Generation		28%
Transportation		25%
Heating uses		
Industrial heating	23%	47%
Residential heating	24%	
Total		100%

The unit for total energy consumption in the economy is the "quad." The quad is defined as "one quadrillion Btu (10^{15} Btu)." Total energy consumption is often expressed in quads in order to assure a number of reasonable size. The total energy consumption in the United States in 1975 was about 73 quads. In recent years the consumption of energy has increased about 4% per year.

Figure 3 shows the rapid growth of total U.S. energy consumption over a period of approximately 100 years. This condition has led to depletion of naturally occurring energy sources such as fossil fuels. Conservation measures are needed to slow down the growth rate.

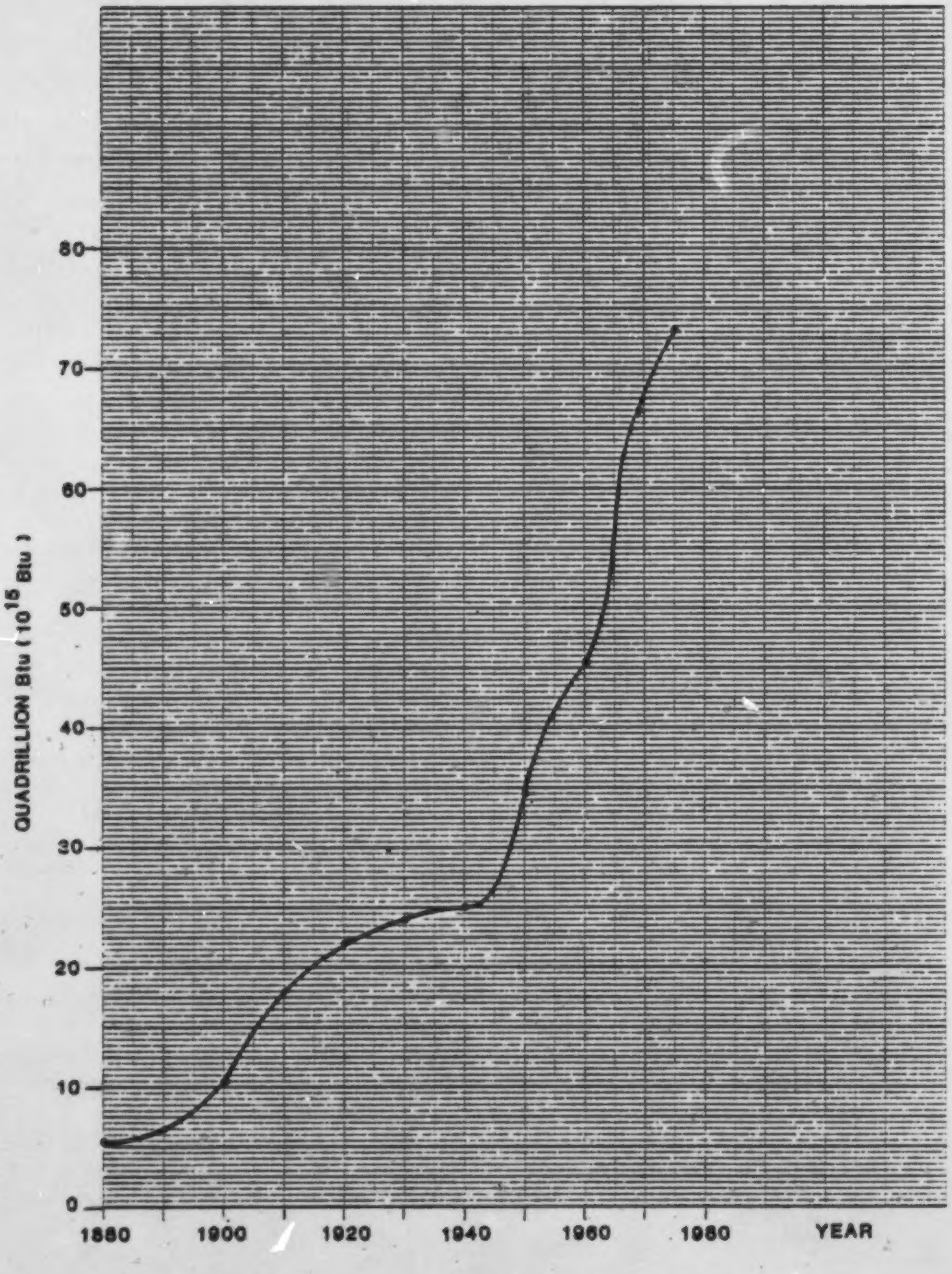


Figure 3. Growth of Energy Consumption.

NECESSITY OF ENERGY CONSERVATION

One obvious reason for interest in energy conservation is the economic savings that can be achieved. The costs of energy are increasing rapidly. Figure 4 shows the price trend for the cost of natural gas that is delivered to a residential user. To keep costs down, energy conservation must be practiced by business and industry, as well as individual consumers. Moreover, as energy prices continue to rise, the economic motivation for energy conservation will become stronger.

There is another, more compelling reason for energy conservation: the total supply of fossil fuels is limited. Fossil fuels, such as coal, oil, and natural gas, provide most of the energy used in the United States, but only a finite supply of fossil fuels is available. When these fossil fuels are used, they will be gone forever.

According to estimates by M. K. Hubbert*, the utilization of a fuel with a limited total supply follows a pattern: first, a rising period of growth, then a peak, then a decline. The peak is reached at a time when 50% of the total supply has been used. Usage declines to near zero as the supply becomes exhausted. According to Hubbert's estimates, the year of peak consumption for the world's petroleum supply will be 1990. At that time half of all the world's available petroleum will have been used. By 2020, 90% of the total petroleum will have been used, and the consumption will have declined. Figure 5 shows a schematic diagram of the usage of petroleum by the human race. The exact location of the peak and end positions in the diagram may be

---

*M. K. Hubbert, Resources and Man, W. A. Freeman and Co., San Francisco (1969).

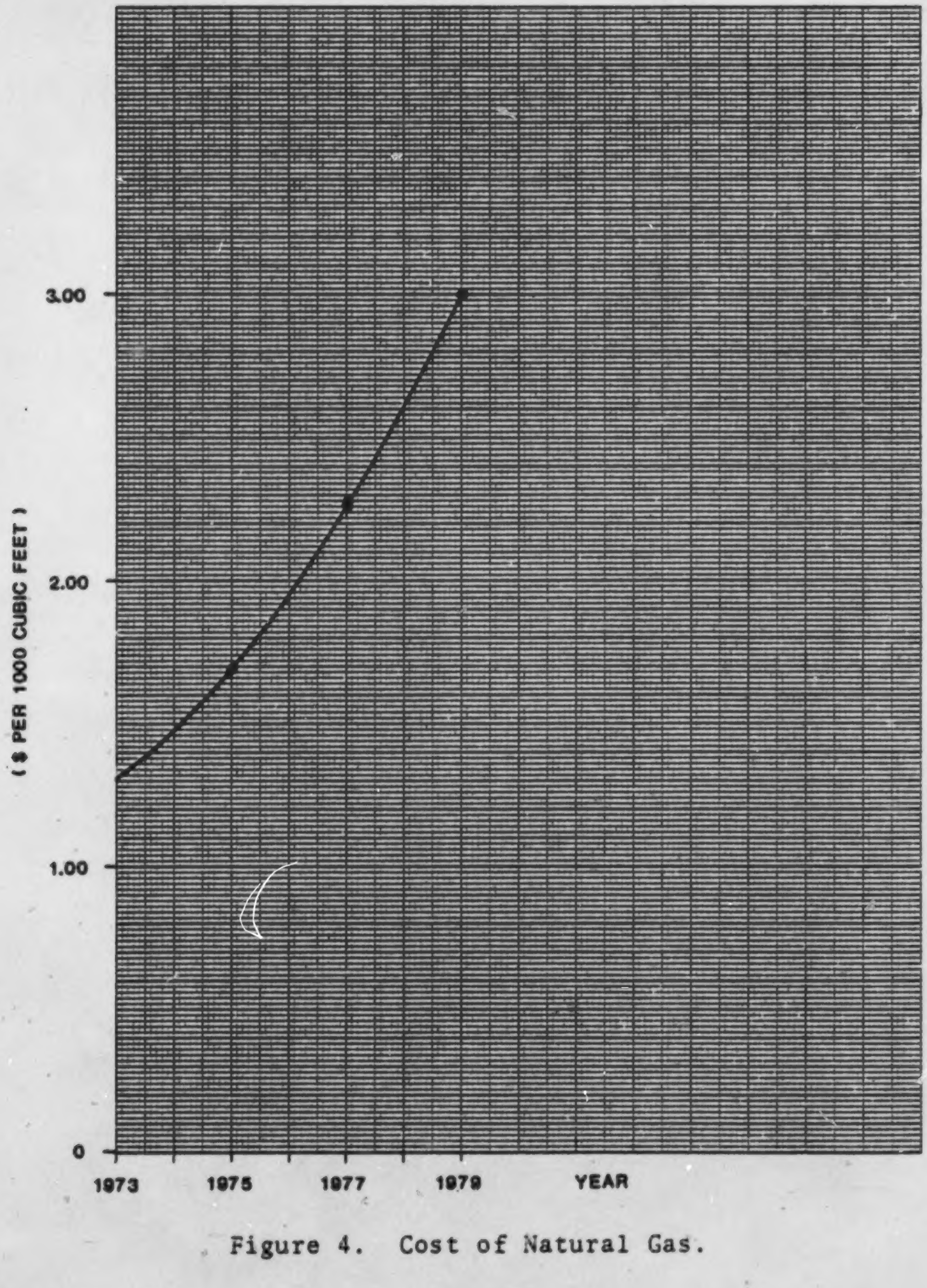


Figure 4. Cost of Natural Gas.

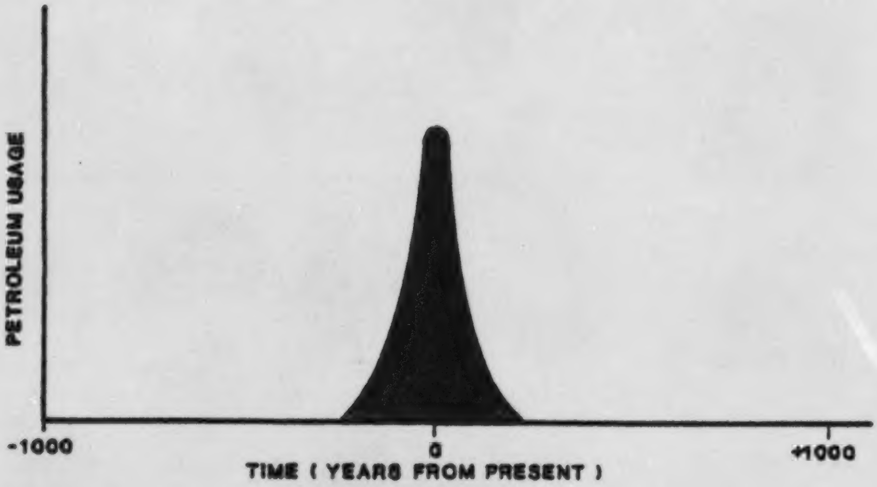


Figure 5. History of Human Usage of Petroleum.

somewhat debatable; still, the basic fact emerges that the petroleum age will be a brief period of human history.

Conservation efforts will stretch the available supply of energy and, at the same time, will allow time to develop other renewable sources of energy. Some of the technologies now under development, such as solar energy and thermonuclear fusion, have been discussed in the Energy Production Systems course. Such technologies offer hope for the future when fossil fuels are exhausted. Still, conservation measures will continue to be important, even when such advanced energy sources are operational, the reason being that energy growth occurs at an exponential rate (e^{Rt}). If the usage now is expressed as U_0, the usage at a time years in the future, U(t), is shown by the following equation:

$$U(t) = U_0 e^{Rt} \qquad \text{Equation 1}$$

The above figure is for a growth rate of R per year. According to Equation 2, the time (in years) that it will take for the usage to double (td) is given as follows:

$$t_d = \ell n \frac{2}{R} \approx \frac{0.693}{R} \qquad \text{Equation 2}$$

In Equation 3, R is given as a fraction. If R is to be expressed as a percentage, the following is true:

$$t_d \approx \frac{69.3}{R(\%)} \qquad \text{Equation 3}$$

As a rule of thumb, the numerical factor 69.3 is often rounded off to 70. For an example, at a growth rate of 5% per year (an apparently modest rate), usage will double in 14 years. In another 14 years it will double again — to four times the original rate. This exponential growth is sketched in Figure 6, demonstrating that, even for a growth rate of 5% per year (a rate that does not seem large), the total energy use will grow enormously within several decades.

Thus, it is not enough simply to seek new energy sources. The exponential growth of energy use will overwhelm the capabilities of promising new technologies. The development of energy sources must be accompanied by energy conservation in order to hold down the exponential growth of energy use.

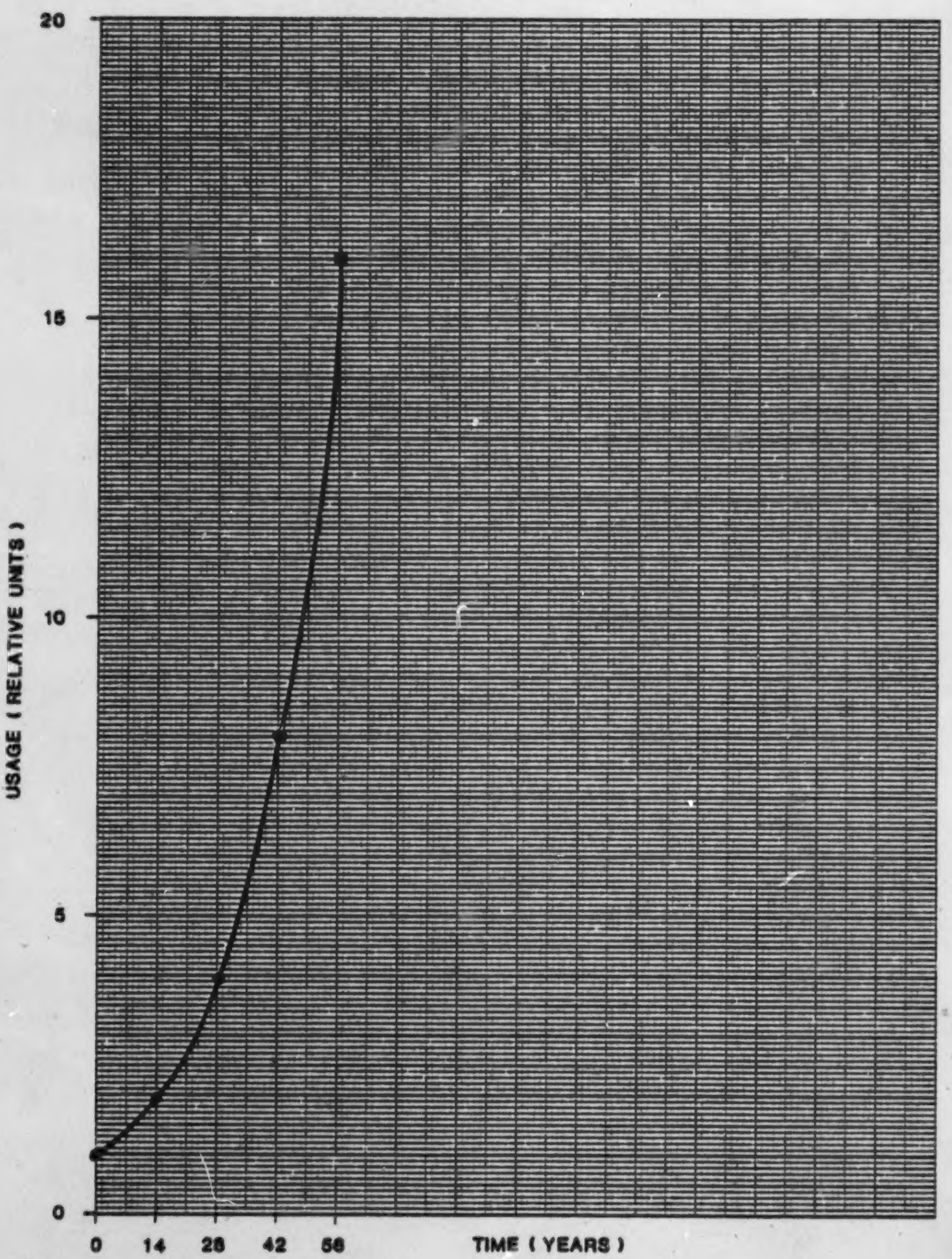


Figure 6. Growth of Energy Usage at a Rate of 5% Per Year.

PATTERNS OF ENERGY USE AND COST

The general pattern of energy use in the United States has been upward. The growth rate may be estimated from the data shown in Figure 3. Using Equation 1, the following may be obtained:

$$\ell n \left[\frac{U(t)}{U_0}\right] = R\ t \qquad \text{Equation 4}$$

or

$$R = \frac{1}{t}\ \ell n \left[\frac{U(t)}{U_0}\right]$$

The above figure extends from 1960-1969, a period that may be regarded as typical since the growth of energy usage was not constrained by considerations of an energy crisis. Over this nine-year period total energy consumption increased from 45.5 quads to 66.7 quads. If these numbers are substituted into Equation 4, the following may be obtained:

$$R = \frac{1}{a}\ \ell n\ \frac{66.7}{45.5} = \frac{1}{9} \times 0.3825 = 0.0425 = 4.25\%$$

Equation 5

This growth rate of 4.25% means that the total energy consumption would double about every 16 years. A 4% per year growth rate has also been typical for many of the individual components of energy usage (petroleum usage, electrical power generation, and so forth); therefore a 4% pattern seems to have been set.

Apparently, even the realization that there is an energy crisis has not helped reduce the growth rate. Figure 7 shows gasoline consumption over the 1950-1978 period. Gasoline consumption decreased slightly in 1974, following the Arab oil embargo; but then it began increasing again at a rate similar to the rate before 1973. The net effect was simply a two-year offset in the rising curve.

Although providing statistics is not the intent of this module, it is significant to note that the pattern of energy consumption in still other areas has been similar. For instance, the growth rate for electrical power has been approximately 4% per year (through 1978). Obviously, the American public has not learned the importance of energy conservation.

There are some indications that the growth rate decreased in 1979; but, as of this writing in early 1980, the statistics were not fully available. In 1979 there were rapid increases in the prices of gasoline and heating oil. In the same year, emergency controls were imposed on temperature settings in public buildings. These factors may have contributed to the decrease in growth rate because the growth in gasoline usage and electrical power production, in particular, slowed somewhat in 1979. It remains to be seen whether this will be a lasting trend.

The costs of fuels are expected to increase in the future. Figure 8 shows some estimates for the cost of oil, natural gas, and coal through 1990. Of course, such estimates are subject to many uncertainties. The political situation in the Middle East, for example, can have a significant effect on the price of oil. It is clear that the costs will continue to increase and will eventually force energy conservation on everyone.

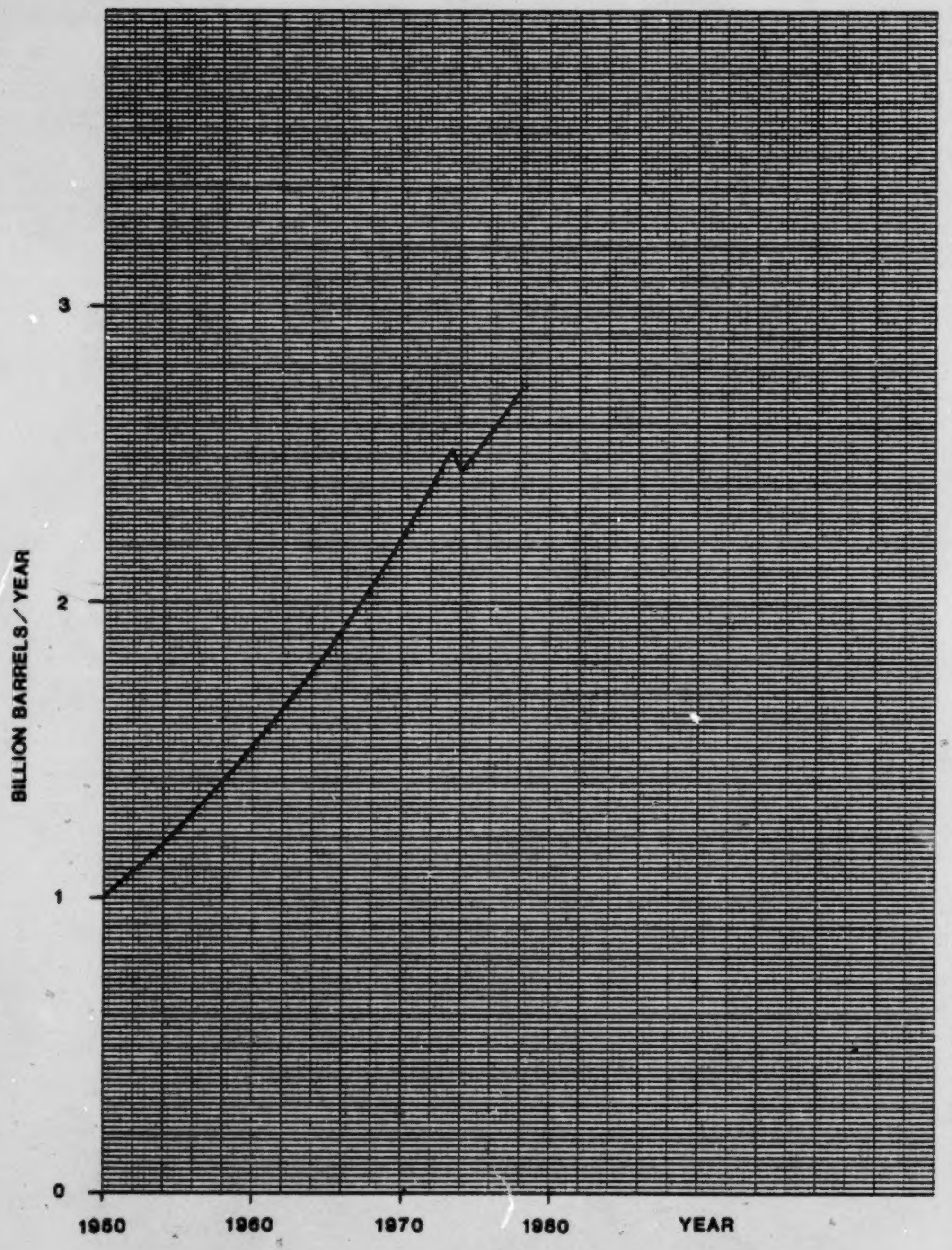


Figure 7. Gasoline Consumption.

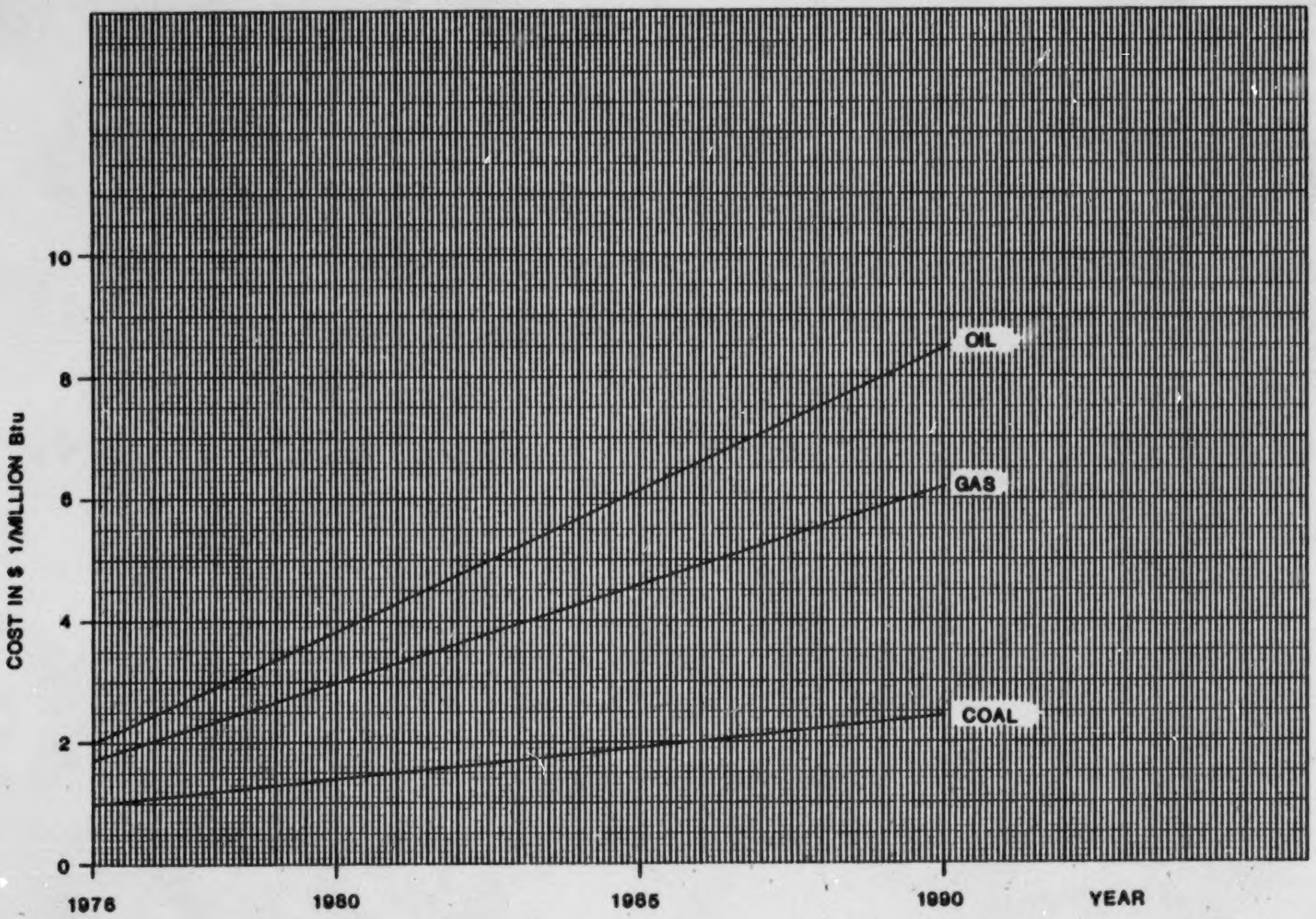


Figure 8. Estimated Energy Values Vs. Time.

The values presented in Figure 8 are presented in terms of costs per million Btu in order to keep costs of different fuels on a comparable basis. Pricewise, the three fuels are expected to keep their relative rankings, with oil being most expensive, natural gas second, and coal least expensive. Over the period between 1980 and 1990, prices are expected to increase as follows:

- Oil – 2.55
- Natural gas – 2.39
- Coal – 1.78

There are numerous other factors which affect future energy usage, such as those listed below:

- Laws and regulations
- Effects on the environment
- Costs associated with energy conservation

Laws and Regulations

The use of energy and its costs are strongly affected by governmental actions. For many years the United States government regulated the costs of natural gas and oil produced in the United States by controlling the maximum price that could be charged for these two fuels. In the late 1970s, the prices were deregulated and controls were removed, leading to increases in the costs of energy.

The government also influences energy use through taxation. Tax credits are offered to encourage energy conservation; for example, credits on personal income tax are offered to homeowners who add energy-conserving facilities (such as insulation) to their homes.

Environmental Effects

Environmental considerations can influence energy costs. For example, generation of electrical power with coal as a fuel sometimes involves adverse environmental effects. Burning of coal that has a high sulfur content releases sulfur dioxide into the atmosphere. This can be extremely undesirable, leading to so-called "acid rains" which harm forest life and endanger fish life in some lakes. Extra equipment must be added to smokestacks to reduce sulfur dioxide emission – which, of course, increases the cost of burning coal as compared to other fuels.

Costs of Energy Conservation

There are costs associated with energy conservation. For example, if a homeowner adds insulation and weatherstripping, there undoubtedly will be cost savings involved; however, insulation and weatherstripping cost money to buy and install. For the energy savings to be worthwhile to the homeowner, the cost of the materials must be less than the money saved on fuel.

The relation between total energy cost and the cost of fuel is shown schematically in Figure 9. As fuel is saved by energy conservation measures, the cost of the fuel decreases. At the same time, the associated costs increase. The initial fuel savings usually are relatively inexpensive. But as one approaches zero fuel usage, it becomes more expensive to increase the fuel savings. The other costs include both capital cost (the price of the insulation, for example) and interest on the money invested. Total cost of

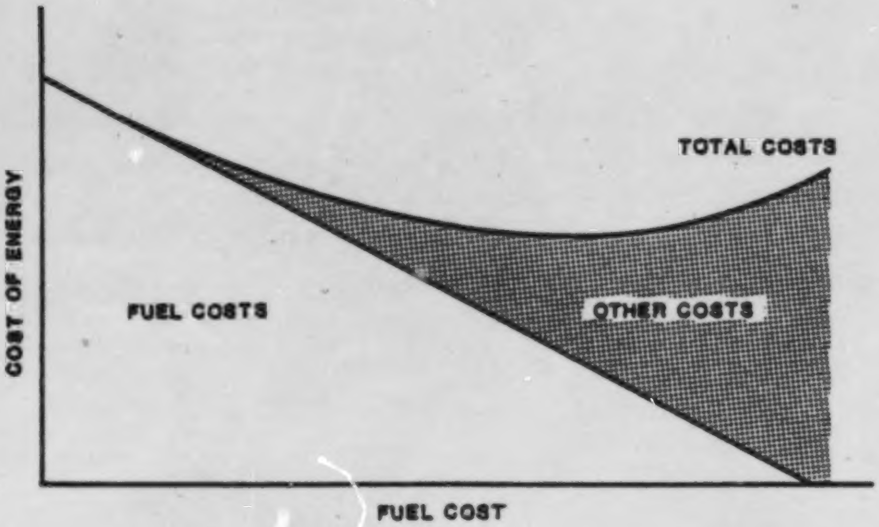


Figure 9. Cost of Energy Vs. Fuel Cost.

energy service is the sum of the fuel cost and the other investment needed to save the fuel. Total cost shows a minimum at some intermediate value of fuel usage.

ESTIMATION OF FUEL CONSUMPTION

In many cases it is important to be able to estimate the total amount of energy that will be needed for heating or cooling a specific building. The estimate will allow an adequate amount of fuel to be available, as well as provide a basis for estimating future energy costs. The estimate will also allow fuel to be ordered at a rate to match expected consumption.

The most widely used and simple method of estimation is the degree-day method. Other, more sophisticated methods have been developed, but the degree-day method gives useful results in many practical cases. For estimates of heating, the degree-day method assumes that heating in a building is desirable when the average outdoor temperature falls below 65°. For a particular day, the number of heating degree-days is the number of degrees that the average daily temperature is below 65°. Thus, if the average temperature on a given day is 45°F, that day has 20 heating degree-days (65 - 45 = 20). If the average temperature is 65°C or greater, then that day has zero degree-days.

The concept of heating degree-days is useful because the relation between fuel consumption and degree-days is approximately linear. Thus, on a day with 40 degree-days, twice as much fuel will be used as on a day with 20 degrees. In addition, the number of degree-days is cumulative over a period of time. The total number of degree-days for a month is the sum of the number of degree-days for each day in the month.

As stated above, a temperature of 65°F is used as the basis for the degree-day method. In 1979, an emergency presidential order required that the maximum temperature to which public buildings may be heated is 65°F. Because heat is released by sources other than the furnace (electric lights, for example), heating should not be needed until the outdoor temperature reaches some value below 65°F. This fact may lead to some modification of the basis for the degree-day method. However, as of 1980, this modification has not yet occurred.

Weather records are available for locations throughout the United States. Table 3 presents the average number of heating degree-days for a number of cities. Values are presented for each month, and also for the total heating season, which runs from July through the following June.

TABLE 3. AVERAGE NUMBERS OF DEGREE DAYS.

City	Heating Degree Days													Cooling Degree Days
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	June	Yearly Total	Yearly Total
Boston	0	9	60	316	603	983	1088	972	846	513	208	36	5634	784
Chicago	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882	1035
Dallas	0	0	0	62	321	524	601	440	319	90	6	0	2363	2590
Denver	0	0	90	366	714	905	1004	851	800	492	254	48	5524	641
Detroit	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232	864
Honolulu	0	0	0	0	0	0	0	0	0	0	0	0	0	4459
Los Angeles	0	0	6	31	132	229	310	230	202	123	68	18	1349	1315
Miami	0	0	0	0	0	65	74	56	19	0	0	0	214	4371
Minneapolis	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382	737
New York City	0	0	30	233	540	902	986	885	760	408	118	9	4871	1191
Phoenix	0	0	0	22	234	415	474	328	217	75	0	0	1765	3904
St. Louis	0	0	60	251	627	936	1026	848	704	312	121	15	4900	1415
Seattle	50	47	129	329	543	657	738	599	577	396	242	117	4424	185
Washington D.C.	0	0	33	217	519	834	871	762	626	288	74	0	4224	1550

The total amount of fuel needed for a given period increases linearly with the number of degree days. Thus, for a heating season, almost twice as much fuel would be needed for a given building in New York City (4871 degree-days) as for one in Dallas (2363 degree-days).

The values in Table 3 are averages over a period of years for each location. The values will fluctuate from year to year according to the mildness or severity of the weather. Values are often published in local newspapers, both for the current day's value and for the cumulative total.

The amount of fuel may be estimated from the following equation:

$$E = \frac{H \times D \times 24}{T \times E_f \times H_v} F \qquad \text{Equation 6}$$

where:

E = Total amount of fuel needed for a period of time in which there will be a total of D degree-days.

H = Heat loss (given in units of Btu/1 hr).

D = Degree-days.

T = Temperature difference (in °F) between the indoor temperature and the design outdoor temperature for which the value of heat loss H is applicable.

E_f = Efficiency of the furnace (expressed as a decimal fraction). Values around 0.75-0.80 are typical.

H_v = Heating value of the fuel (expressed in Btu per unit volume).

F = Correction factor.

Values of H must be known for the particular building size, type of construction, amount of insulation, and so forth. Some methods for estimating values of H will be presented in Module EC-02, "Conservation Principles and Efficiency Measurements – Space Heaters." Values for H_V were presented in Energy Production Systems.

The factor F is a correction factor that accounts for the fact that the outside temperature is not always at the design temperature, and for the fact that the equation applies strictly to the case of the furnace being ON all the time, whereas, in fact, the furnace will actually cycle ON and OFF. In practice, the value of F is often close to one. For purposes of this module, it will be assumed that F is equal to one. For more exact measurements, a more accurate value of F should be used.

EXAMPLE A: ESTIMATING NATURAL GAS REQUIREMENTS.	
Given:	Assume that the design heat loss of a small office building in Minneapolis for a particular heating season is 500,000 Btu/hr for a design temperature of -15°F outdoors and 65°F indoors. The natural gas has heating value of 1050 Btu/ft^3, and the furnace has an efficiency of 80%.
Find:	Estimate the amount of natural gas required.
Solution:	According to Table 3, the total number of heating degree-days in Minneapolis is 8382 for a full heating season. Substituting the appropriate values in the equation gives the following:

Example A. Continued.

$$\text{Fuel consumption} = \frac{500{,}000 \times 8382 \times 24}{[65-(-15)] \times 0.8 \times 1050} \times 1$$

$$= 1{,}497{,}000 \text{ ft}^3.$$

Equation 7

This is the estimated amount of natural gas needed for the heating season.

The estimates of energy needs by the degree-day method will vary according to the practices and habits of the building's occupants. The degree-day method has the advantage that fuel consumption rates are reasonably constant for a given number of degree-days. The fuel used over a period that has 100 degree-days will be the same – whether the 100 degree-days are accumulated within only a few days or are spread over a longer period. Thus, estimates based on actual experience may be made for a particular building. The amount of fuel used in a period of time is measured, and the number of degree days in that period are obtained from weather records. Then, based on average weather records (as represented by Table 3), fuel needs for future periods can be estimated.

The degree-day method may be expected to give estimates that are reasonably accurate for many cases. Improved estimates may be obtained with more sophisticated methods that have been developed in recent years.

The degree-day method is also used to estimate cooling loads. This can serve as a measure of air conditioning requirements. For estimates of cooling, the degree-day method is based on the assumption that air conditioning is desirable when the maximum temperature rises above 80°F. The number of cooling degree-days is defined as "the difference between the average daily temperature and 65°F." Thus, if the average daily temperature is 75°F, there will be 10 cooling degree-days. For the average temperature to be 75°F, presumably the maximum temperature will have exceeded 80°F. For days on which the average temperature is 65°F or below, the degree-day total is zero.

The basis of the cooling degree-day measurement is 65°F. The 1979 emergency presidential order requires that minimum indoor temperatures in public buildings be maintained at 78°F during the warm part of the year. This fact, presumably, would affect the calculation of cooling degree-days, and could affect the choice of the base temperature of 65°F. As of 1980, the definition of the cooling degree-day has not yet been changed.

Values for the average annual total number of cooling degree-days for a number of cities are presented in Table 3. The use of the simple cooling degree-day method for estimating cooling requirements is undoubtedly an oversimplification. It does not take into account factors such as humidity. When relative humidity is high, more air conditioning may be needed to maintain comfort. A composite index, combining temperature and humidity, has been suggested as providing a more accurate measure of cooling requirements.

CONSERVATION IN ENERGY-USING EQUIPMENT

There are many common devices and systems which use energy in homes, offices, factories, and other buildings. These include the following:

- Heating, cooling, and ventilating systems
- Hot water and steam supply systems
- Lighting systems
- Industrial equipment (such as electric motors)

HEATING, COOLING, AND VENTILATING SYSTEMS

The heating or cooling system should be matched to the building. When energy was relatively inexpensive, some designers would habitually specify a heating or cooling system too large for the space. A heating or cooling system which is too large can waste energy.

Proper tune-up and maintenance of a heating and cooling system are needed to ensure that it performs with good efficiency. These are two of the greatest possible sources for energy conservation.

HOT WATER AND STEAM SYSTEMS

In homes and office buildings, a significant fraction — approximately 15-20% — of energy usage is for heating water. In industry, where steam is widely used for processing materials, the percentage may be higher.

Today's hot water and steam temperatures may be set too high since temperature standards which were set long ago when energy conservation was not a serious issue may still be in effect. In view of this, proper temperatures should be re-established, and controls should be reset to comply with modern-day requirements.

Temperatures of hot water or steam should be lowered at night or at times of minimum use. Automatic controls which turn the temperature up and down, as needed, can save important amounts of energy.

LIGHTING SYSTEM

In some cases, buildings are lighted excessively. This is another energy wasting practice that is attributable to an era when light energy was inexpensive and the illumination engineer could error "on the safe side" and specify high levels of lighting. Now, with energy costs rising, the illumination engineer must specify actual light levels needed for safety and proper work performance.

Unnecessary lighting is a thing of the past. Imaginative programs which reduce and control lighting of buildings are now widely used.

INDUSTRIAL EQUIPMENT

Many varied types of industrial equipment use energy. One specific example is an electrical motor. Proper maintenance of this motor or any similar equipment can save energy. Moreover, equipment can be selected to suit the load, assuring optimum efficiency. In addition, certain operations can be rescheduled in order to control peak demand.

By employing proper equipment selection, optimized operating procedures, and good maintenance, the industrial user can improve the usage of energy by electric motors and other equipment.

CONSERVATION IN BUILDING CONSTRUCTION AND USE

Much of the energy consumed in the United States is used for heating or cooling of buildings — homes, offices, factories, and so forth. Heating and cooling are employed to help maintain human comfort inside the buildings when the outside temperature is either low or high. Even when a building is empty, some heating or cooling may be needed. For example, a home must be heated during winter to avoid the damage that can occur when water pipes burst. Thus, there are great opportunities for energy savings related to building heating and cooling. These opportunities will be discussed in later modules in this course.

The main thrust of energy conservation in building heating and cooling is prevention of heat transfer between inside and outside — which involves various methods of insulation. The heat transfer issue will be discussed in view of the following aspects:

- Sealing of heat leaks
- Building construction
- Heating and cooling equipment operation

SEALING OF HEAT LEAKS

Heat is transferred through many surfaces and structures within a building. Specifically, heat from a building that is being heated in winter may be lost due to the following structures:

- Roof
- Walls
- Floor

- Windows
- Doors

The common approach is to add insulation and weatherstripping to reduce heat loss. The type of insulating material varies for each of the structures listed above. Details for insulation requirements will be presented in Module EC-02.

BUILDING CONSTRUCTION

For an existing building, one conserves energy by measures such as adding insulation, storm windows, and so forth, and by improving furnace efficiency. But for a new building, there are other measures which can improve energy efficiency. These can range from simple factors such as the direction the house faces to elaborate ones such as the construction of an earth house (buildings covered with a layer of earth on all but the south side).

A relatively easy measure of conserving energy for any new building is to utilize south-facing windows which will collect solar energy during the day. In addition, it is relatively easy and inexpensive to upgrade insulation and install storm windows in new construction.

Other design modifications become more elaborate, including items like solar walls and panels, solar hot water heating, multiple zone furnaces, and construction of earth buildings. In general, the technology is available to construct buildings that reduce energy consumption. The added construction costs are usually relatively small and are offset in a short time by energy savings.

HEATING AND COOLING EQUIPMENT OPERATION

The methods of using available heating and cooling equipment can be improved to provide significant savings. Simply turning the thermostat down in winter or up in summer is an important energy-saving measure. Moreover, proper maintenance and tune-up of the heating or cooling system is important — as was discussed earlier. This includes not only the furnace and cooling unit, but the following accessory equipment:

- Ducts
- Piping and tubing
- Vents and louvres
- Filters
- Dampers

An energy management plan, with controls to stop and start the equipment on a programmed schedule, can provide savings. Heating equipment can be turned on automatically in the morning when heat is needed, and turned off automatically when heat is not needed.

At times when temperature and humidity are appropriate, further savings can be achieved by use of outdoor air. Fans can bring outdoor air inside, or mix outdoor air with heated or cooled indoor air. However, to do this, sensing devices are needed for both indoor and outdoor conditions, and automated devices are needed to mix the outdoor air in proper proportions. Such devices can rapidly pay for their cost.

Thus, proper use of heating and cooling equipment can lead to substantial energy savings without sacrifice of human comfort.

CONSERVATION IN TRANSPORTATION

According to Table 2, about 25% of the energy usage in the United States is for transportation. This category includes private automobiles, commercial transportation services (airlines, railroads, and so forth), and farm machinery. Because of the large amount of energy involved, there are many important possibilities for energy conservation in the transportation field.

Most of the vehicles used in the United States, and virtually all the automobiles, are powered by internal combustion engines. In an internal combustion engine, the fuel is burned inside the engine in a confined volume. This produces high pressure gases which expand to move a piston, which, in turn, causes a shaft to rotate. The internal combustion engine differs from heat engines in which the fuel is burned outside the engine.

The greatest opportunities for energy conservation in the transportation field involve the automobile fleet, which consists of tens of millions of vehicles mainly owned by individual owners. Because the ownership of automobiles is so widespread, there are probably fewer opportunities for energy conservation technicians in the automotive field. In addition, there is already a specialized body of technical personnel involved in the care and maintenance of automobiles: auto mechanics. Thus, detailed training in conservation of energy in the automotive field is outside the scope of this course, and there is not a separate module devoted to this subject.

However, because of the important savings of energy that can be achieved with respect to automobiles, some of the important possibilities will be briefly mentioned. The approaches to energy conservation involve choice of car and equipment, maintenance, and driving habits.

CHOICE OF CAR AND EQUIPMENT

Obviously the first possibility involves choice of an automobile with good mileage capabilities. Mileage figures for automobiles are published by the Environmental Protection Agency and are widely advertised by automobile manufacturers. Because actual mileage will vary, depending on the individual's use and driving habits, the published numbers cannot be relied on as absolute numbers. Rather, they should be considered as a relative comparison between different models of automobiles.

The choice of accessory equipment will affect mileage. An automobile with a standard manual shift transmission will deliver higher mileage than the same model with an automatic transmission. Addition of many powered options (power brakes, power steering, air conditioning, and so forth) will reduce mileage.

It is also well established that radial tires offer improved mileage, as compared to more conventional bias-ply tires.

MAINTENANCE

Proper maintenance of an automobile can considerably increase gasoline mileage. Regular engine maintenance, including the electrical system (spark plugs and cables, distributor points and timing, and so forth) and the fuel system (carburetor operation) can maintain good mileage. One misfiring spark plug can substantially reduce mileage. The emission controls should also be properly maintained to ensure good mileage. There is no question that addition of emission controls has had an adverse effect on mileage; however, the emission control systems are needed to help maintain clean air. These controls perform their function best when they are properly serviced and maintained.

Tires should be properly inflated since under-inflated tires have increased rolling resistance and, therefore, decrease fuel economy. Improper inflation – under-inflation or over-inflation – will lead to excessive tire wear and decreased life. Wheel alignment should also be properly maintained since misalignment can lead to decreased mileage.

DRIVING HABITS

Proper driving habits can increase fuel economy. Mileage decreases as speed increases (beyond about 40 miles per hour). The 55-mph speed limit was adopted primarily to help conserve gasoline, and adherence to this law has resulted in reduced fuel consumption.

Acceleration from a stopped position to normal driving speed can influence fuel economy. A high-acceleration "jackrabbit" start is wasteful of fuel. A light touch on the accelerator is beneficial; and such "feather-footed" driving can improve gas mileage.

During highway driving, a constant speed should be maintained as much as possible, with an even pressure on the gas pedal. Stops should be anticipated, so that the car approaching a stop light can gradually coast to a stop. A quick stop wastes gasoline.

This above discussion is by no means a complete guide to the saving of gasoline in automobiles. Rather, it summarizes briefly some of the important approaches to fuel economy.

EXERCISES

1. Describe the flow of energy in the U.S. economy, including the following:
    a. The nature of the primary sources
    b. The energy conversion devices
    c. The end uses
    d. The losses
2. If the use of a particular resource is increasing at a rate of 7% per year, approximately how long will it take for the use of the fuel to double?
3. State at least three reasons for energy conservation.
4. Describe the long-term historical use of petroleum in the past, present, and future.
5. Discuss the costs of natural gas, fuel oil and coal, and the expected price trends for each.
6. In a large office building in Detroit, a total of 50,000 gallons of fuel oil is used for heating in the period October-November. About how much fuel oil may be expected to be used in the period December-March?
7. Describe the historical pattern of energy usage in the U.S.
8. Discuss methods of energy conservation in the following areas:
    a. Energy using equipment
    b. Building construction and use
    c. Automotive transportation
9. Carry out procedures to estimate fuel usage for a specific building, based on observations made by the student.

LABORATORY PROCEDURES

In this exercise, the student will need to have access to data which shows how much fuel a particular building uses during part of the heating season. This could be the student's home, a school building, a small office, or a store.

1. Measure the fuel usage over a three-day period. The measurement may be any of the following:
   a. Measure the reading of the gas meter.
   b. Measure the level of fuel oil in the storage tank.
   c. Measure the reading of the electric meter.

   Make measurements at the beginning and end of the period.
2. Estimate energy that was used for purposes other than heating the building. For example, natural gas may be used in stoves, ovens, gas clothes dryers, and so forth. Estimates for average energy consumptions of such items may often be obtained from the local utility company. For electrical devices, the rating – in watts – is usually stated on the device. Estimate the amount of time each item is used and multiply this by the use rate in order to obtain an estimate of the total energy used by such items. Subtract this from the total usage to obtain the amount of energy used for heating the building.
3. Obtain the actual number of heating degree-days in the immediate locale during this three-day period, as well as the average annual number of degree-days. These numbers may be obtained from the weather service if they are not listed in the local newspaper.

4. Divide the energy used for heating in the three-day period by the actual number of degree-days within that three-day period. This figure gives the energy consumption per degree-day.

REFERENCES

ASHRAE Handbook of Fundamentals. New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1977.

Curran, S. "Energy Resources Available to Man." Physics in Technology (July 1977) vol. 8, p. 137.

Derven, R. "Heat Pumps." Popular Science (September 1976) p. 92.

Fisher, J. C. Energy Crises in Perspective. New York: John Wiley and Sons, Inc., 1974.

Jones, T. H. "How to Figure the Best Places to Cut Heat Loss in Your House." Popular Science (September 1975) p. 97.

Lees, A. "Home Insulation." Popular Science (September 1976) p. 130.

Wilbur, D. E. "The Potential for Energy Conservation in Buildings." ADL Impact Services Document L770902 (September 26, 1977).

TEST

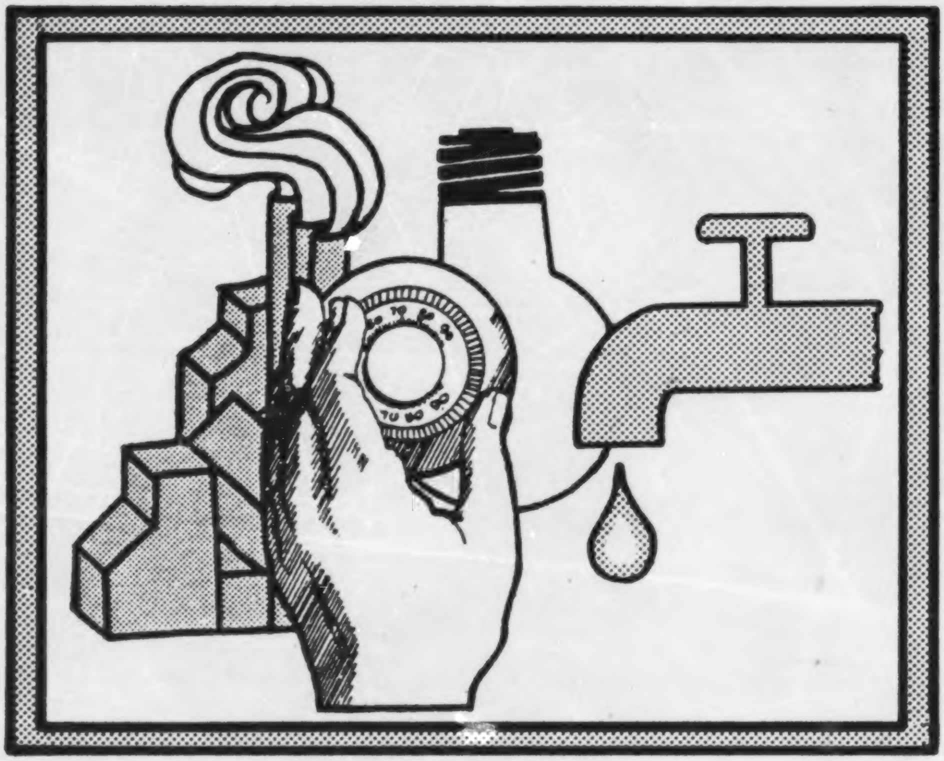
Fill in the blanks.

1. The prime sources of energy in the U.S. economy are petroleum, _______ _______, __________, ___________, and ____________.
2. The main end uses of energy in the U.S. economy are heating, __________, and ________ ________.
3. If the use of a resource is increasing at 10% per year, it will take _____ years for the total usage to double.
4. Of coal, natural gas, and petroleum, the most expensive (per unit of heat energy) is __________, and the least expensive is __________.
5. According to estimates by M.K. Hubbert, by the year 2020 about _____% of the total world supply of petroleum will have been used.
6. The number of degree-days on a particular day is the number of degrees that the average daily temperature is below _____ °F.
7. Suppose that a certain building requires 10,000 gallons of fuel oil for heating in November, when there are 600 degree-days recorded. In this case, if December has 900 degree-days, ________ gallons of fuel oil will be used.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-02

CONSERVATION PRINCIPLES AND EFFICIENCY MEASUREMENTS - SPACE HEATING

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

© Center for Occupational Research and Development, 1981

This work was developed under a contract with the Department of Education. However, the content does not necessarily reflect the position or policy of that Agency, and no official endorsement of these materials should be inferred.

All rights reserved. No part of this work covered by the copyrights hereon may be reproduced or copied in any form or by any means — graphic, electronic, or mechanical, including photocopying, recording, taping, or information and retrievals systems — without the express permission of the Center for Occupational Research and Development. No liability is assumed with respect to the use of the information herein.

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

"Conservation Principles and Efficiency Measurements — Space Heating" presents practical techniques for conserving energy in heating systems. Energy conservation is discussed as it applies to the following aspects of a system:

- Improved furnace operation
- Control of outdoor air
- Improved heating coil operation
- Control of fan operation
- Individual room control

Several measurement and analyses techniques are presented, as well as methods and procedures for improving system efficiency and reducing heat loss.

This module particularly emphasizes energy savings that can be achieved with automation and control of the heating system. With controls, the system supplies only as much heat as is required and supplies the heat only when and where it is actually needed.

When energy was once considered plentiful, wasteful design philosophies were often incorporated into heating systems. Heat was supplied liberally, without concern for how much energy was wasted. However, this approach is no longer valid since actual heating needs of a building can now be evaluated and regulated. Heating functions can be controlled so that heat is delivered only to the parts of the building where it is needed, and only when it is needed. Thus, the heating schedule can be adjusted to the occupancy of the building, including such things as morning startup, evening shutdown, janitorial schedules, and weekend and holiday hours. Large savings in energy are possible without modification to the building or to the heating system simply by proper control of system operation. The techniques to accomplish this will form the main part of this module.

Relatively minor modifications to the heating system can also save energy. For example, changing the dampers on the outdoor air inlet to reduce leakage can be significant. This module will describe such modifications.

The major issues of building construction and materials will be referred to later in Module EC-07. Module EC-07 will discuss such things as adding insulation and storm windows in order to reduce heat loss in existing buildings, and factors such as choice of site and type of construction in order to reduce heat loss in buildings to be constructed.

This module will emphasize public and commercial buildings, rather than homes. The general features of energy conservation in homes are similar, of course; but because of size, home heating systems are less adaptable to many of the control measures which will be presented. The main thrust in this module will be concerned with the heating systems of buildings, such as offices, factories, schools, hospitals, apartment buildings, warehouses, and so forth.

The procedures presented in this module are compatible with the comfort of the occupants. This is an important factor. If the comfort of the people in the building is not maintained, the morale and productivity of the workers may drop. This would be a loss that would more than offset the possible energy savings. Thus, the control measures to be described will help eliminate wasteful and unnecessary uses of heating energy, but, at the same time, will maintain the needed comfort level of the building occupants.

PREREQUISITES

The student should have completed one year of high school algebra, Unified Technical Concepts I, II, and III, Fundamentals of Energy Technology, and Energy Production Systems.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List, describe, and explain conservation methods related to the following:
    a. Improved furnace operation.
    b. Control of outdoor air.
    c. Improved heating coil operation.
    d. Control of fans.
    e. Individual room control.
2. Perform calculations related to energy savings produced by the following:
    a. Improved furnace operation.
    b. Control of outdoor air.
    c. Improved heating coil operation.
    d. Individual room control.
3. Prepare an energy survey for a specific building.
4. For a particular furnace, determine the following:
    a. If the furnace is oversized.
    b. The flue gas temperature.
    c. The flue gas composition.
    d. The furnace efficiency.

CENTRAL BUILDING CONTROL

Many of the conservation methods described in this module rely on control of the heating system to direct the heat only to areas where it is needed and at times when it is needed. This may be done according to a time schedule, or it may involve a response to changing conditions. The temperatures at various locations in the building may have to be measured and used as input to the control system.

Heating in a small building is relatively easy to control. In a home, for example, one thermostat often controls the entire system. This thermostat may be operated manually (for instance, set back to a lower degree at night); or it may be replaced with a clock thermostat which will reset the thermostat at fixed times each day. For small buildings, there is no need for a sophisticated central control.

Large buildings may consist of hundreds of rooms, each with its own thermostat. Motorized dampers in the ducts could be added to the system to control the flow of heated air since the demands for heat may vary in different parts of the building. In such a case, manual reset of the individual thermostats is obviously impractical. Individual automated thermostats at each location would be more expensive than a central controller. They would also be less efficient because each thermostat would respond only to the needs of the individual area that it serves, not to the needs of the entire system.

The development of centralized automated control systems can provide an effective means for energy management in a reasonably large building. Such centralized systems can monitor the needs of all parts of the building and, at the same time, provide increased efficiency in the use of the heating plant. Such systems have become popular in recent years, mainly because of the increased emphasis on energy conservation, but also because of technological advances in small computers. Small computers capable of controlling a building heating system have developed rapidly in sophistication without their cost becoming too prohibitive. Thus, an improved computer technology has aided in automation of building heating.

A centralized building control system under the control of a small computer can accept inputs from many measuring devices, monitor conditions in different parts of the building, and control the operation of all components in the heating system (boiler, heating coils, dampers, fans, and so forth). The complete function of a building heating system can thus be optimized; that is, comfort can be maintained in occupied parts of the building with a minimum expenditure of energy.

In addition to controlling the heating system within a building, the central control system also can be used to monitor and automate many other functions, such as the following:

- Building air conditioning
- Operating schedules of other equipment in the building
- Control and limitation of peak electrical demand
- Monitoring of fire alarm systems
- Monitoring of building security systems

A centralized energy management system does more than just save energy by adjusting individual independent thermostats. The central controller gives the information needed to analyze and reduce the energy consumption for heating. It can tie together all the energy-using components (boilers, chillers, motors, pumps, fans, dampers, lighting, and so forth) into a single system. The controller centrally collects building operating data on a real-time basis, processes the data, and then automatically exercises the needed control over all parts of the system. Complicated timing schedules, such as varying occupancy in different parts of the building on weekends, during holidays, and so forth, can be utilized by the controller, Again, the net result is better control over energy waste and reduced total energy expense.

The control system operates automatically. It does not require the attention of an operator. At the same time, the control system has the flexibility of manual override by the operator when necessary. It can also present to the operator information on conditions in all parts of the building. The information can be presented as a printout from a teletypewriter or as a display on a television screen.

As a rough approximation, consider that a central building control system might become attractive when the total floor area of a building exceeds 100,000 square feet. This value can be higher or lower, depending on patterns of building occupancy and on the presence of specialized equipment. Consider, too, that although buying an individual control system for smaller buildings may not be practical, contracting for an automated control system from companies that provide such services to customers on a time-sharing basis may be practical.

STRUCTURE OF HEATING SYSTEMS

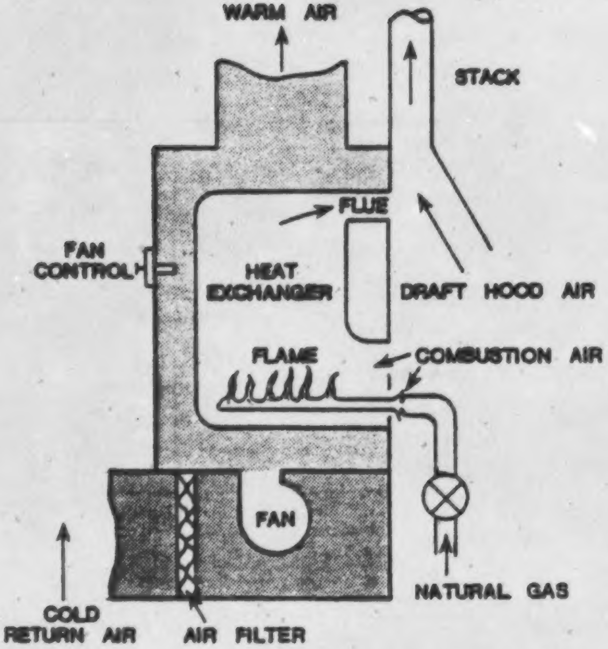
There are several types of heating systems in use. Although each has features that are unique, many similarities are often encountered. Some of the more common types of heating systems will be described in the next few pages.

In some cases, the heating system is integrated into a total system which also includes cooling and ventilation. Naturally, this type of system is called a heating, ventilating, and air conditioning (HVAC) system. Although this module basically is concerned with heating, some systems consist of functions of heating, ventilating, and air conditioning which are so tightly interrelated that the heating part cannot be described separately. Any discussion of this type of HVAC system within this module will necessarily include some description of the components used for cooling.

Heating systems may involve transfer of a heated medium from the furnace to the area which is to be heated. Media which are commonly used include warm air, hot water, and steam. The working medium used in a HVAC system is usually warm air. Many of the HVAC systems which do rely on circulation of warm air are used in offices, factories, schools, and so forth. Therefore, the following paragraphs emphasize warm air systems.

The furnace is the heart of a heating system. Figure 1 shows a schematic diagram of a typical gas-fired warm air furnace. The gas is mixed with air for combustion and burned in the burner section. The hot products of combustion exchange their heat in the heat exchanger section and warm the air — which is then circulated to the space that is to be heated. The air comes from the cold air return duct, returning from the heated space. The combustion products are exhausted through the flue and up the stack. To ensure proper exhaust of the combustion products, some draft air also flows up the stack. This is done to keep combustion products from re-entering the building. The system in Figure 1 produces warm air which is circulated directly to the areas (space)

Figure 1. Schematic View of Gas-Fired Forced Warm Air Furnace.


WARM AIR
STACK
FLUE
FAN CONTROL
HEAT EXCHANGER
DRAFT HOOD AIR
FLAME
COMBUSTION AIR
FAN
NATURAL GAS
COLD RETURN AIR
AIR FILTER

that need heat. Cool air from the space is returned through the return air ducts to the furnace for reheating.

Other approaches involve exchanging the heat from the combustion products to heat water. The water may be heated and circulated as hot water, or it may be boiled and circulated as steam. For direct heating, hot water or steam may be circulated through radiators located in the space to be heated. However, radiators are not often used in modern public buildings. A common approach is to use a method which allows the water to be heated through exchange with the combustion products and then the resulting hot water or steam to flow through coils. The air that is to go to the space flows around the coils to be warmed; then it is circulated to the space. This system involves a boiler, where the water is heated, and coils, where the air is warmed by contact with the surface of the coils. The design and structure of boilers are described in the course entitled Energy Production Systems. The structure of two types of heating coils is shown in Figure 2. As hot water or steam flows through the interior of the coils, air flows over the outer surface of the serpentine coils and is warmed. The warm air is then used for space heating.

The chamber containing the heating coils is sometimes called a hot deck. (Similarly, a chamber containing cooling coils to cool air is called a cold deck.)

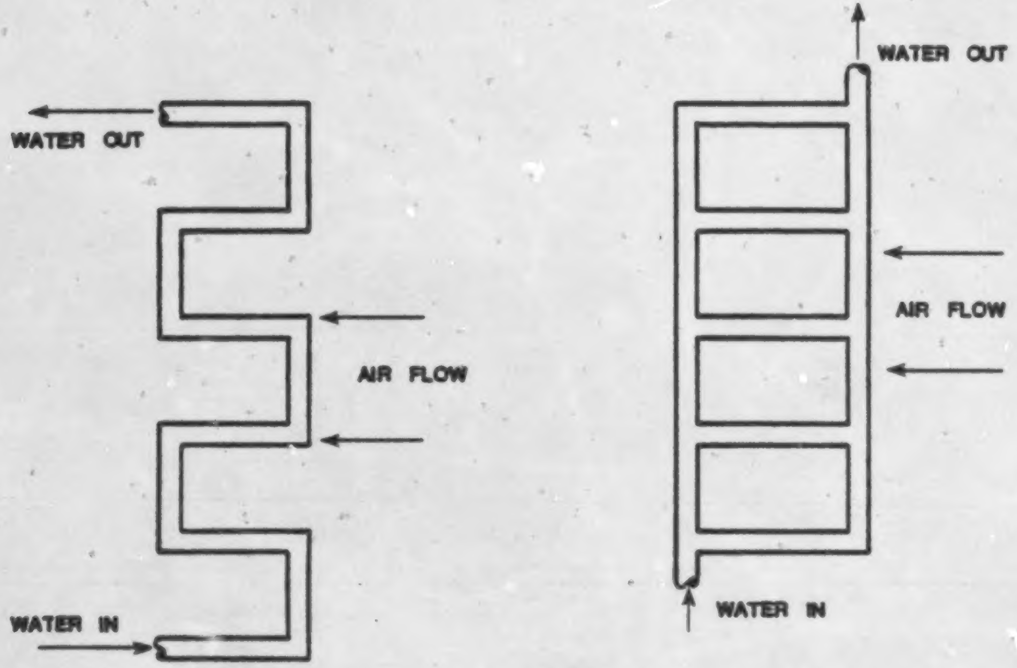


Figure 2. Typical Coil Arrangements.

The following is a list of eight components that comprise this type of heating system:

1. Fans, which circulate air through ducts.
2. Dampers, which open and close to allow air to flow through a duct or to be closed off. In an automated system the dampers may be driven by motors.
3. Inlet and outlet registers, through which heated air flows into the space to be heated and cooler air returns from the space.
4. Thermostats, which control the demand for heat in a particular space. A common type of thermostat consists of a bimetal strip that is composed of two different metals in contact with each other. As the temperature changes, the two metals expand at different rates, causing the strip to bend (Figure 3). This bending determines whether an electrical contact is made or broken and thereby controls the operation of fans, dampers, furnaces, and so forth. In practice, bimetal strips are wound into spirals rather than straight strips.
5. Water pumps, which control the flow of water and pump water from the boiler to the heating coils.
6. Heating coils, which are filled with water heated by the furnace. Air flows over the surface of the heating coils and is warmed. Heating coils usually have serpentine forms in order to provide a larger contact surface for heat exchange to the air. Some examples were shown in Figure 2.
7. Valves, which open and close off the flow of water in certain parts of the system according to demand. The valves may be electrically actuated in automated systems.

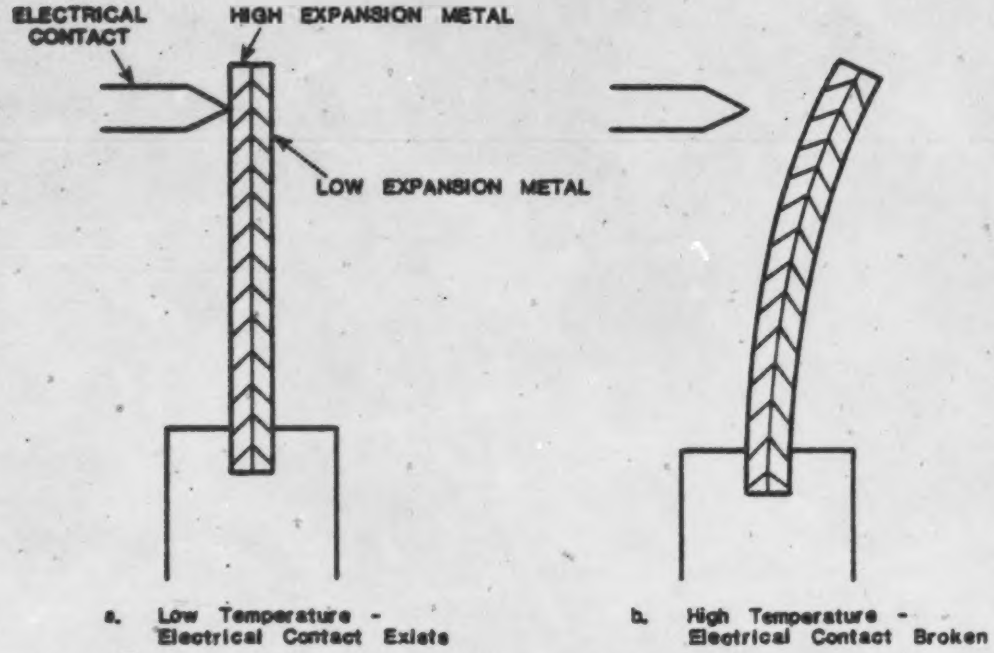

ELECTRICAL CONTACT
HIGH EXPANSION METAL
LOW EXPANSION METAL
a. Low Temperature - Electrical Contact Exists
b. High Temperature - Electrical Contact Broken

Figure 3. Bimetal Strip.

8. Filters, which are used to clean the air flowing through the ducts.

Perhaps the most common HVAC system is the single-duct, single-zone system, illustrated in Figure 4. Intake air is heated through heat exchange with the heating coil and is then circulated to the heated space by the fan. The temperature may be controlled by varying the temperature of the heating coil, or by turning the system on and off. There may be a preheat coil, especially in very cold climates. The heating coil and preheat coil are supplied with hot water or steam from the boiler.

Cool air returns through the return air register. Part of the return air may be recirculated through the heating

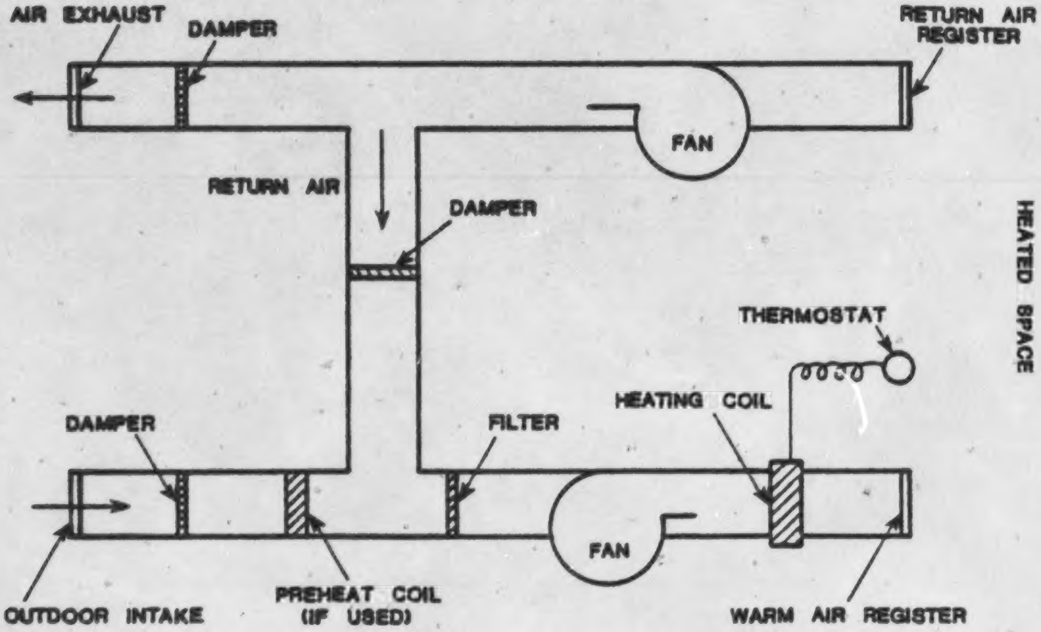

AIR EXHAUST
DAMPER
RETURN AIR REGISTER
FAN
RETURN AIR
DAMPER
HEATED SPACE
THERMOSTAT
HEATING COIL
DAMPER
FILTER
FAN
OUTDOOR INTAKE
PREHEAT COIL (IF USED)
WARM AIR REGISTER

Figure 4. Single-Zone System.

coil. In winter, of course, the return air will be warmer than outdoor air.. To reduce heating requirements, as much return air should be utilized as possible; however, some make-up air from outdoors must be used to satisfy ventilation requirements. The flow rates in the different parts of the system are controlled automatically by the dampers.

Single-duct, single-zone systems may have problems supplying uniform temperatures in a large building since heated air must flow a longer distance through the ducts to reach the most distant part of the building. In this case the heated air cools slightly along the way, and the result is uneven heating.

Terminal reheat systems were devised to overcome the problem of uneven heating. First, the heating coil produces air that is warmed to a common temperature – often 55°F.

Then the air receives additional heat from reheat coils located near the place where the air enters the space to be heated. The boiler supplies the reheat coils with hot water or steam. The temperature in each area (zone) to be heated is controlled by the thermostat for that zone; in other words, each thermostat acts on its reheat coil to produce the desired temperature for the zone. A system that uses terminal reheat – where the temperature of each zone may be controlled independently – is illustrated in Figure 5. Zone optimization for saving energy in terminal reheat systems is described later in this module.

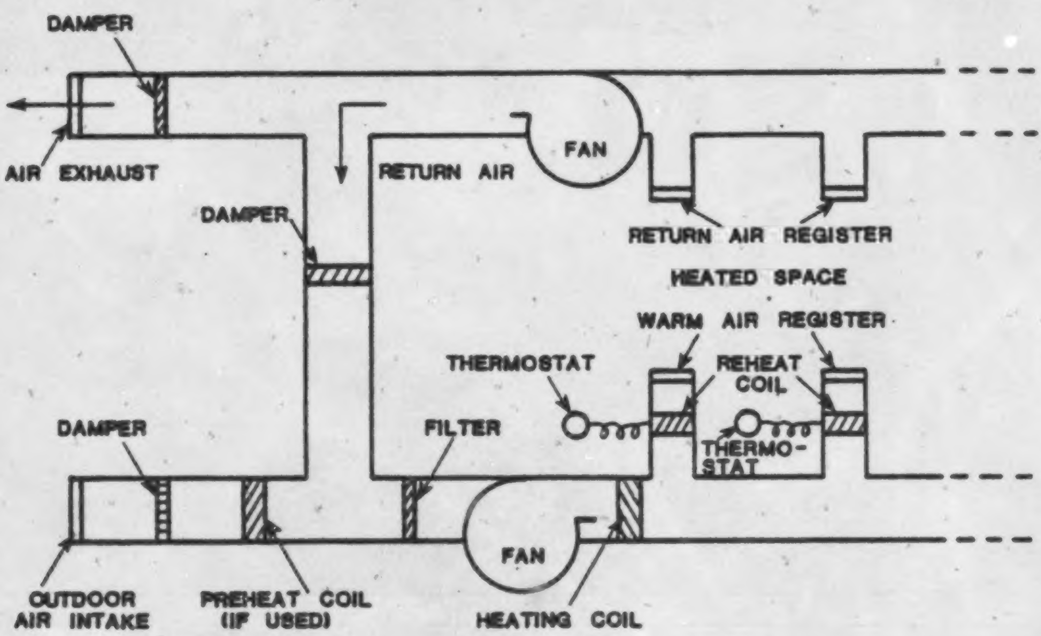

DAMPER
AIR EXHAUST
RETURN AIR
FAN
DAMPER
RETURN AIR REGISTER
HEATED SPACE
WARM AIR REGISTER
THERMOSTAT
REHEAT COIL
DAMPER
FILTER
THERMO-STAT
FAN
OUTDOOR AIR INTAKE
PREHEAT COIL (IF USED)
HEATING COIL

Figure 5. Terminal Reheat System.

A multi-zone system, illustrated in Figure 6, offers another method of controlling temperatues independently in each area of the building. This type of system is an example of

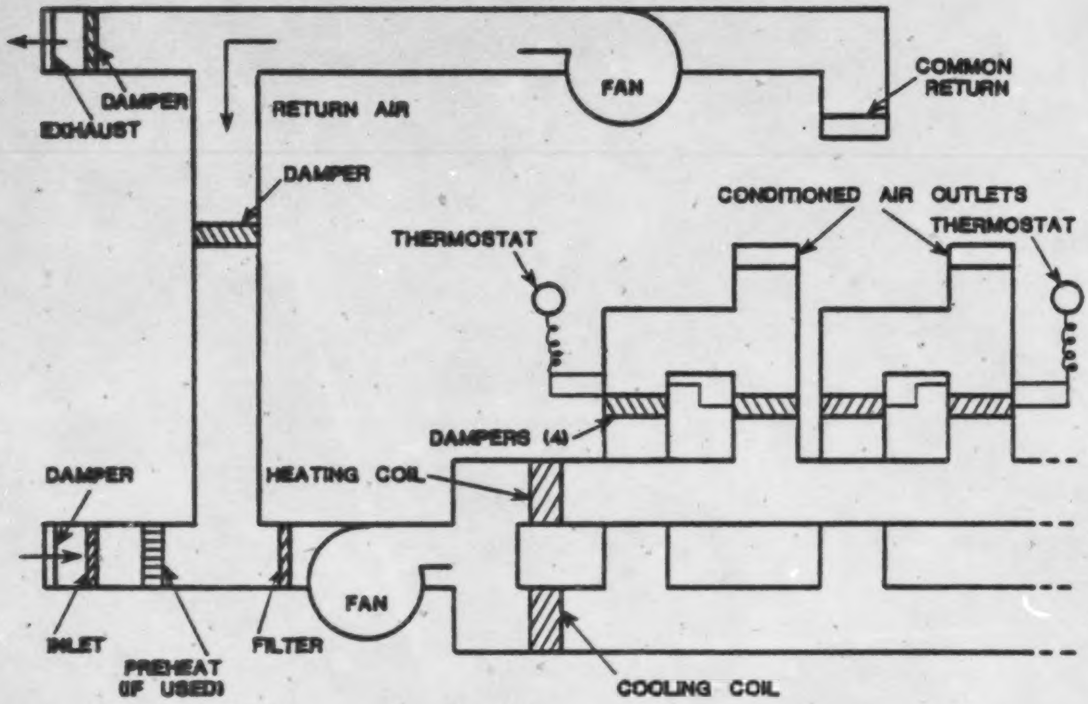

EXHAUST
DAMPER
RETURN AIR
FAN
COMMON RETURN
DAMPER
CONDITIONED AIR OUTLETS
THERMOSTAT
THERMOSTAT
DAMPERS (4)
DAMPER
HEATING COIL
INLET
PREHEAT (IF USED)
FILTER
FAN
COOLING COIL

Figure 6. Multi-Zone System.

the intermixing of heating and cooling functions. Heated air is produced by the heating coils and cool air is produced by the cooling coils. Both heated air and cool air are delivered to each area and mixed in the proper proportions to produce the desired temperature. The thermostat controls the dampers, which are the devices that mix the air.

Multi-zone systems are potentially wasteful. Energy must be used to provide both cooling and heating; but when the air is mixed, part of this energy expenditure is nullified and part of the energy is wasted. Proper adjustment of the system – which will minimize energy waste – will be described later in this module.

Dual-duct systems also intermix the heating and cooling functions. Both heated and cooled air are carried to the space, and the temperature of the space is controlled by the relative amounts of each of these two components that are allowed to enter. The thermostat controls the operation of the dampers. A dual-duct system (Figure 7) differs from a multi-zone system in that separate ducts are used to deliver the warmed and cooled air.

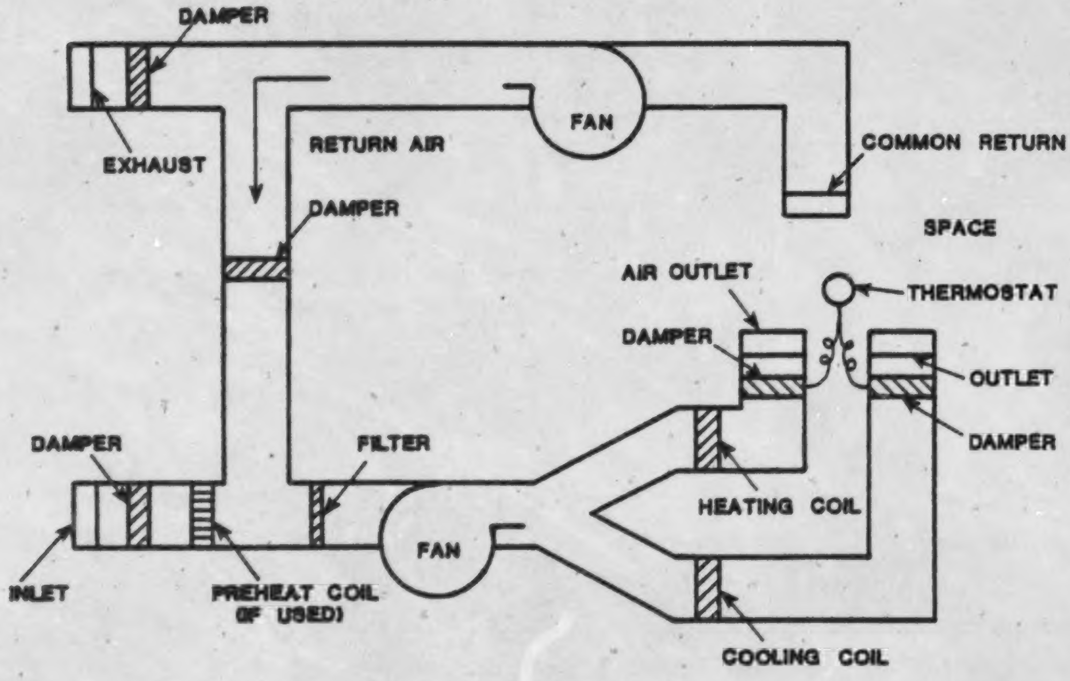

DAMPER
EXHAUST
RETURN AIR
FAN
COMMON RETURN
DAMPER
SPACE
AIR OUTLET
THERMOSTAT
DAMPER
OUTLET
DAMPER
FILTER
DAMPER
HEATING COIL
FAN
INLET
PREHEAT COIL
(IF USED)
COOLING COIL

Figure 7. Dual-Duct System.

Like the multi-zone system, the dual-duct system is potentially wasteful of energy. Proper control of the system is essential to prevent this from occurring. Again, methods to minimize energy waste will be described later in this module.

Variable-air-volume systems are similar to single-zone, single-duct systems; but they offer improved control over the temperature in different areas of the building. In a variable-air-volume system (Figure 8), the temperature in the space is controlled by the flow rate of the heated air going into the space. The flow through the damper is controlled by the thermostat. This modification of the single-duct system allows separate control of the temperature in each zone by varying the amount of air of constant temperature.

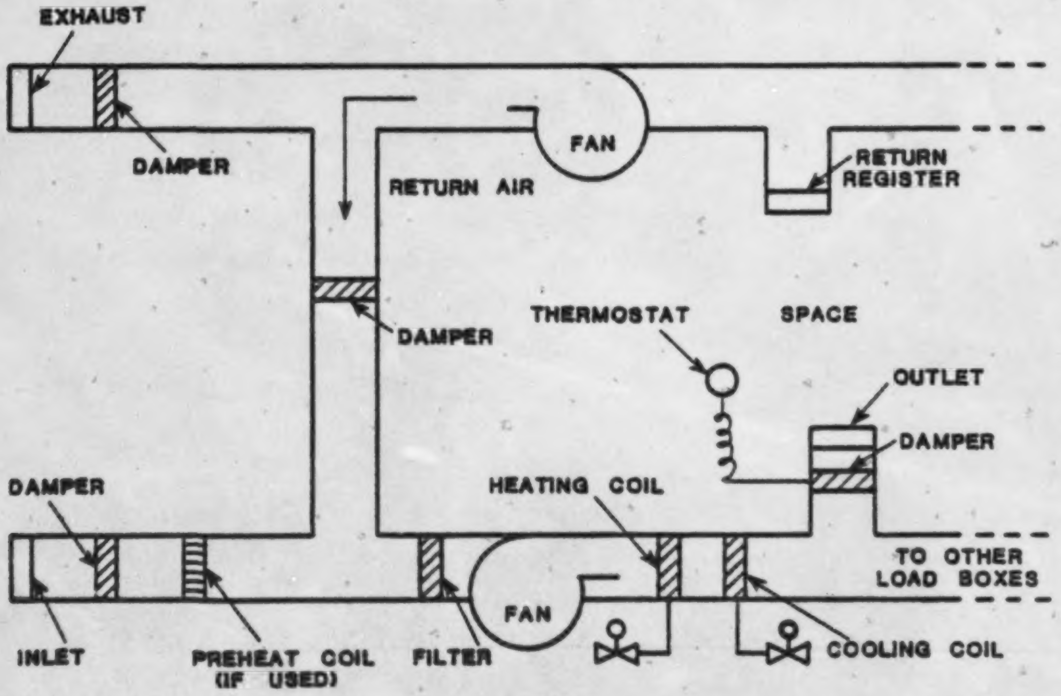

EXHAUST
DAMPER
FAN
RETURN AIR
RETURN REGISTER
DAMPER
THERMOSTAT
SPACE
OUTLET
DAMPER
DAMPER
HEATING COIL
TO OTHER LOAD BOXES
FAN
INLET
PREHEAT COIL (IF USED)
FILTER
COOLING COIL

Figure 8. Variable-Air-Volume System.

The variable-air-volume system offers the potential for energy savings as compared to multi-zone and dual-duct systems. Conversion to variable-air-volume operation is described later in this module.

The preceding discussion of heating systems does not include all systems; there are many other types and variations in use. Furthermore, all heating systems are unique in some way to other systems. Still, the above discussion does illustrate many of the common features that will be encountered in most heating systems.

THE ENERGY SURVEY

An audit of energy use is an important first step in preparing for energy conservation in a specific building. The audit shows where the energy is being used in the building, and it highlights areas where energy conservation might be most effective. This following section discusses a survey of the use of energy for heating. Later, the student will actually prepare a heating energy survey for a building.

A suggested form for an energy survey is presented on the following page. The format used in this form is not the only one in use, yet it will give the student an idea of some of the relatively easy ways for saving heating energy.

As stated earlier, the energy survey provides clues to energy conservation measures that can be implemented within a specific building and HVAC system. Many energy-saving steps will involve little or no extra cost, such as resetting thermostats. Others may require some modification of the HVAC system and, therefore, will involve costs. It is wise to begin with the no cost, or low-cost, steps.

The specific actions required to correct some of the wasteful situations revealed by the survey will be described in later sections.

HEATING ENERGY SURVEY FORM

HEATING EQUIPMENT AND SCHEDULES

SIZE, GROSS SQ FT

AREA HEATED

TYPE(S) OF OCCUPANCY: (% OR SQ FT)

Office______________________________ (Other)__________________

Warehouse___________________________ (Other)__________________

Manufacturing_______________________ (Other)__________________

Retail______________________________

Lobbies & Mall_____________________
(Enclosed)

BUILDING USE AND OCCUPANCY

Fully Occupied: (50% or more of normal)

Weekdays (Hours)____________________to______________

Weekends (Hours)____________________to______________

____________________to______________ Sunday

____________________to______________ Holidays

Remarks: Describe below if occupancy differs for different floors, areas, buildings:____________________________

____

____

Energy Survey Form. Continued.

Heating Checklist for Control System Upgrade

Yes No

DAY OPERATION

☐ ☐ 1. Are thermostats set at 68-70°F or less in public spaces?

☐ ☐ Locked?

☐ ☐ 2. If they are non-locking, is there any provision to keep settings at 68-70°F?

☐ ☐ 3. Does the thermostat work?
When set below 68°F, does valve, damper, or heat source turn on?

☐ ☐ 4. Is thermostat calibrated within 1 to 2°F of setting?

☐ ☐ 5. When set below 68°F, is the cooling source (outside air or refrigeration) locked out?

☐ ☐ 6. Is ZEB (Zero Energy Band) operation provided for?

☐ ☐ 7. Have you reduced outdoor air ventilating quantity when the building is occupied, consistent with standards? (5-10 CFM/person for office areas.)

☐ ☐ 8. Do you shut off exhaust fans in toilets, kitchens, or labs when areas served are unoccupied?

NIGHT/UNOCCUPIED OPERATION

☐ ☐ 9. When unoccupied, is the temperature setting automatically reduced by at least 10°F?

☐ ☐ 10. Are warehouses or storage areas kept at lower temperatures than occupied areas?

☐ ☐ 11. Do you close outdoor air damper when the building is unoccupied?

☐ ☐ 12. Do outdoor air dampers close tightly during night or unoccupied times?

Energy Survey Form. Continued.

Heading Checklist for Control System Upgrade

Yes No

STEAM, HOT WATER, OR ELECTRICAL SYSTEMS FOR SPACE-HEATING

☐ ☐ 13. Have you determined above what outdoor temperature you can shut off heating boilers, heat exchanger pumps and/or electric heat?

☐ ☐ 14. If 13 differs for different buildings, or zones, or times of day, have these parameters been determined?

☐ ☐ 15. Do you have procedures in effect to shut off the heat, as determined under 13 and 14?

☐ ☐ 16. For space-heating hot water systems, have you checked to see if water temperatures or temperature schedules are at or below original design? (Remember that original design temperatures for secondary hot water were based on a 75°F room temperature requirement.)

IMPROVED FURNACE OPERATION

Obviously, the first place to begin energy conservation within the heating system is with the furnace and boiler. This section of the module describes how to get more heat out of each unit of fuel used. The discussion will center on the following four areas:

- Improvement of combustion efficiency
- Reduction of heat losses
- Proper sizing of heating system
- Flue gas damper

IMPROVEMENT OF COMBUSTION EFFICIENCY

Combustion efficiency for a specific furnace and fuel can often be improved. The measurement of combustion efficiency is relatively simple; it involves measurement of the temperature of the gas in the flue and measurement of the composition of the gas in the flue (the content of either O_2 or CO_2).

If the flue gas temperature is high, heat is escaping up the stack. This represents a loss of energy and, therefore, low efficiency since part of the energy from the burning of the fuel is going up the stack, instead of being used to heat the building. The high stack gas temperature may result from use of too much air for combustion, or from dirty heat exchange surfaces.

The flue gas composition is also an important factor. As Figure 1 shows, air from the building is drawn up the flue. It is necessary to have some flow of building air up the stack to ensure that combustion products do not make their way into the building. But too much air going up the stack is wasteful, particularly since this is air that has already cost money to heat.

Excess air is defined as "the amount of air in excess of the amount needed to burn the fuel completely." The amount of excess air may be determined by measuring either the amount of O_2 or of CO_2 in the flue gas. Figure 9 shows the stack concentrations of O_2 and CO_2 versus the excess air for a furnace burning natural gas. (The curves for furnaces burning fuel oil or coal are slightly different.) If one measures either the concentration of O_2 or of CO_2 in the stack gas, the percentage of excess air can be found from this figure.

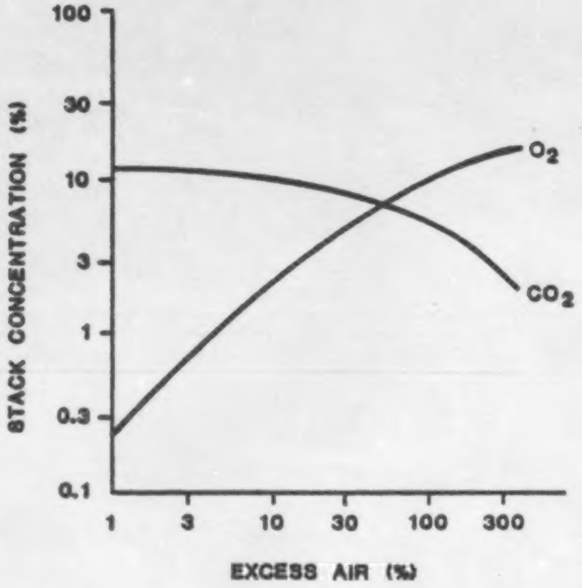


Figure 9. Stack Concentrations for O_2 and CO_2 Vs. Excess Air, for Natural Gas.

It is usually preferable to measure the O_2 concentration, rather than the CO_2 concentration. The excess air determination is relatively insensitive to a CO_2 concentration in the range below 10% – which is the most desirable range. The excess air determination is reasonably sensitive to O_2 concentration in this range.

The measurement of both flue gas temperature and flue gas composition can be done with simple portable analyzers which cost less than \$100. The head of the instrument is inserted into the flue, and the readings for both quantities are displayed on meters. If the meter reads CO_2 concentrations, Figure 10 may be used to convert from a CO_2 concentration to a O_2 concentration. Curves are shown for three different fuels.

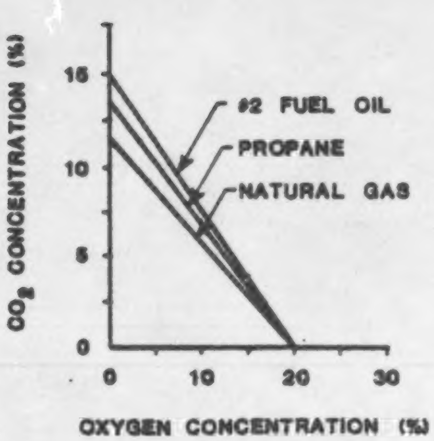


Figure 10. Relation Between Flue Concentrations of CO_2 and Oxygen.

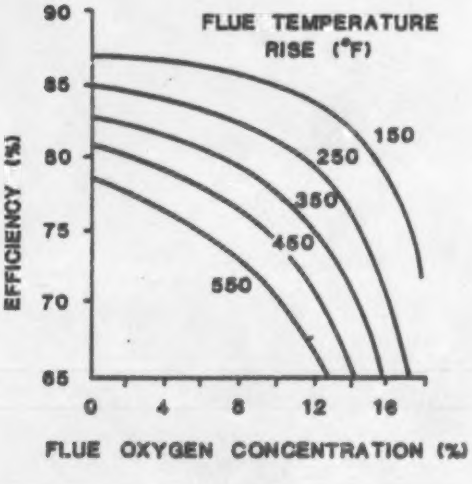


Figure 11. Efficiency Vs. Flue Oxygen Concentration for Natural Gas.

All furnaces for commercial buildings should have routine measurements of flue gas temperature. It is common to find very high values of excess air in furnaces where flue gas is not checked regularly. This represents a substantial waste.

The O_2 concentration should be in the range from 3-5%. Although lower values would give even less heat loss, this would be an unsafe condition since it would be possible for combustion products to enter the heated space. Therefore, it is recommended that oxygen concentrations be confined within the 3-5% range.

Measurements of the flue gas temperature and composition can be used to determine furnace efficiency. The efficiency of a natural gas furnace is shown in Figure 11. This figure shows efficiency versus O_2 concentration and flue gas temperature. The flue temperature rise is the increase in temperature of the flue gas over the ambient temperature in the area of the furnace. Figure 12 shows similar results for a furnace using #2 fuel oil.

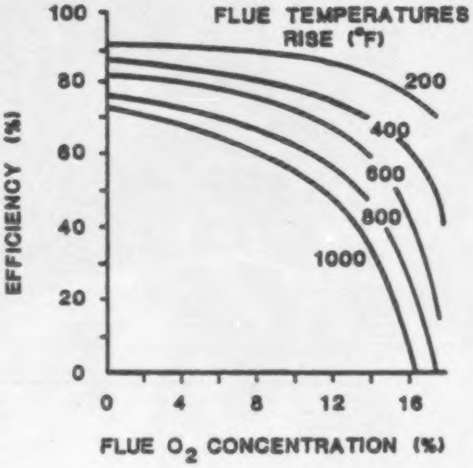


Figure 12. Efficiency Vs. Flue O_2 Concentration for #2 Fuel Oil.

The adjustments to the furnace to improve the flue gas temperature and the oxygen concentration should be made by a qualified person experienced in burner operation. The adjustments involve adjustment of the air-fuel ratio in the burner, adjustment of the linkages which open the fuel valves and the combustion air shutters and valves, change of the controls which regulate the furnace draft and pressure, and, possibly, a retrofit of the burner to achieve better atomization of fuel oil and better mixing of air and fuel. Proper performance of these adjustments requires specialized training and experience that are beyond the scope of this module.

In very large burners, a closed loop control system on the burner may be justified. Such automated systems can measure stack temperature and O_2 concentration, and they use the results continuously to control the furnace operation and to automatically maintain high values of furnace efficiency.

Reduction of Heat Losses

There are a number of possible ways in which heat can be lost from the furnace and boiler. Losses can also originate from the furnace walls and from piping. Another wasteful practice is to use combustion air and boiler feedwater that are colder than necessary since both must be heated anyway. Several techniques for reducing such losses include the following:

- Draw the combustion air from the hottest part of the boiler room.
- Preheat the combustion air by heat exchange with the flue gas.
- Preheat the boiler feedwater by heat exchange with the flue gas.
- Insulate the casing and other furnace parts to prevent loss of heat to the boiler room.
- Insulate piping leading to and from the furnace.

Proper Sizing of Heating System

The furnace size should be no larger than necessary. If the furnace is larger than is needed, it will frequently cycle on and off. During the initial part of the ON cycle, the furnace will be sending hot gas up the stack. Since the building is receiving very little heat while the boiler or the plenum is being warmed, the energy sent up the stack during the warm-up period is lost.

It is more efficient to have the furnace cycle stay ON longer and cycle less frequently. This will reduce the fraction of the time that heat is being sent ineffectively up the stack. A smaller heating system would accomplish this and would save energy.

Basically, the furnace should be just large enough that it will run continuously in the coldest weather encountered at the geographical location. This will produce enough heat to provide adequate heating on the coldest days. At the same time it will reduce the stack losses which result from furnace oversize. In the past, building designers often specified oversized heating systems. When energy was less expensive, this practice was not too impractical. However, oversized heating systems are now expensive wasters of energy.

It may not be economically sensible to replace the entire furnace in an existing building, but there are other measures which can have the same effect. An additional small furnace could be added. This furnace could be used in the warmer parts of the heating season — for example, the early autumn and late spring. This small furnace would run for longer periods at a time and would be more efficient for those periods when the heating load is relatively light. During the colder part of the winter, a larger furnace could be switched in.

Another approach for conserving energy would be to lower the firing rate of the existing furnace. This would have the same effect as previously mentioned: It would make the furnace run a larger fraction of the time and reduce stack losses. The changes in the furnace to reduce the firing rate should be made by qualified, experienced personnel.

These measures will help in cases where the heating system is larger than necessary. Even if the furnace was originally the proper size, when the other conservation measures described here are implemented, the heating requirements will be reduced, and the furnace may then be oversized for the new heating load.

Flue Gas Damper

Even when the furnace is OFF, air can escape up the flue. This is air which has already cost the user money to heat. Installation of a flue damper that closes when the furnace is OFF can reduce this loss.

A flue damper must be installed properly. If the flue damper were to fail in the closed position when the furnace is ON, combustion products would enter the building, creating un-safe conditions.

The flue damper must also be properly designed. A fail-safe type is recommended so that any possible failure will leave in in its OPEN position. Well designed flue dampers are available from a number of companies and should be installed by qualified personnel.

Estimate of Savings From Furnace Improvement

Suppose a certain office building uses 10 billion Btus of heating energy per year, with natural gas used as a fuel. Suppose the stack gas temperature is 530°F, and the flue oxygen concentration is 14%. The temperature in the boiler room is 80°F. How much energy can be saved each year by adjusting the furnace so that the stack temperature is 330°F and the flue oxygen concentration is 5%? At $4 per million Btu, how much money is saved each year?

Figure 11 shows that the efficiency at a flue temperature rise of 450°F (530°F-80°F) and 14% O_2 concentrations is 65%. For the new temperature rise and O_2 concentration (250°F and 5%), the efficiency would be 84% (Figure 11). This means that the fuel usage will be reduced by the ratio 65/84 for a total fuel usage of $65/84 \times 10^{10} = 7.74 \times 10^{9}$ Btu. This figure represents an annual energy savings of $10^{10} - 7.74 \times 10^{9} = 2.26 \times 10^{9}$ Btu $= 2260 \times 10^{6}$ Btu. At \$4 per 10^{6} Btu, this figure represents a cost saving of \$9040 per year.

CONTROL OF OUTDOOR AIR

The introduction of outdoor air into buildings is needed for both safety and human comfort. This air is called make-up air. The amount of make-up air is expressed in units of cubic feet per minute (often abbreviated as cfm). Make-up air in industrial buildings is needed to replace air that is exhausted. Exhaust of air is required to remove fumes and odors and to make up for air used in combustion processes. The amount of make-up air that is required is often specified by local laws and regulations. In homes, there usually are no special efforts made to exhaust air and replace it with make-up air. Usually there is enough air leakage to provide air to replace the oxygen used up by human beings and by combustion processes (cooking, hot water heating, and so forth).

In winter the make-up air must be heated. Proper control of the make-up air, thereby reducing the make-up air to minimum amounts needed, is an effective method for conserving energy. This saves the energy that would be needed to heat the make-up air from the outdoor temperature to the indoor temperature.

The following are several aspects involved in the control of make-up air:

- Reduce minimum outdoor air
- Low leakage dampers
- Reduction of ventilation during unoccupied periods
- Control of exhaust air

Reduce Minimum Outdoor Air

Before the energy crisis, the amount of outdoor make-up air that was specified was conservatively chosen to be fairly high. The amount of make-up air was usually specified as a set amount per unit area of floor space in the building. This amount tended to be unnecessarily high, and it required extra heating. More recently, standards adopted by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) have aimed at a more realistic evaluation of the amount of air that is really needed. Reducing the intake of outdoor air to that value saves energy. For an office building, the suggested values are in the range of 5-10 cfm per person in the building. For an industrial building, the requirements depend on the activities in the building. For example, if there are chemicals and fumes generated, safety may require that more make-up air be used.

The procedure for reducing make-up air is to adjust the inlet damper, through which the outdoor air enters the building. The make-up air should be reduced to the lowest amount that is needed.

Careful measurements are needed to compare the damper position to the amount of air that actually enters the building. The amount of air entering the building can be determined from temperature measurements, and also from a knowledge of the air handling capacity of the fans in the return air portion of the heating system. This value will be specified by the equipment manufacturer. The amount, A, of make-up air entering the building is given by the following equation:

$$A = C \times \frac{T_r - T_m}{T_r - T_o} \qquad \text{Equation 1}$$

where:

C = Air handling capacity of the system, in cfm.
T_o = Outdoor temperature.
T_r = Air temperature in the return air system.
T_m = Temperature of the mixed air (make-up air mixed with return air).
A = The value, in cfm.

For a given damper position, three temperatures are measured: T_o, T_r, and T_m. Then the above equation is used to calculate A. This calibration is needed to determine how the damper actually works and how much air it actually allows in at a given setting.

Low Leakage Dampers

At times, the damper that normally admits outdoor make-up air into the building should be closed. The damper should be closed when the building is unoccupied, for instance. In addition, the outdoor air temperature may drop below some prescribed temperature in some locations, and the damper should be closed.

Many dampers allow leakage, even when they are closed. This leakage allows extra unwanted cold air into the building, and extra heat is required in this instance. Some dampers allow from 5% to 30% leakage, even when they are supposedly closed, adding unnecessary demands on the heating load.

Low-leakage dampers can reduce leakage to less than 1%. Using these types of dampers constitutes a low cost modification that can reduce wasteful leakage.

Reduction of Ventilation During Unoccupied Periods

It is possible to save energy by closing off outside ventilation air during periods when the building is unoccupied. Some fan systems must run even when the building is unoccupied in order to maintain the night temperature, but they are not designed to reduce the amount of outside air intake, even when the outside air is not needed for ventilation. This extra air is unnecessary, and heating it is wasteful; therefore outside make-up air should be supplied only when it is required.

An automated controller or a time clock should be added to the system to shut off the outside air during unoccupied periods and start up the system again shortly before occupancy. The obvious result would be a lower use of energy to heat unneeded outside air.

Control of Exhaust Air

Exhaust air fans often operate longer than is necessary. Exhaust air fans have two main purposes: (1) removal of odors or fumes and (2) removal of excess heat build-up. If the fans are controlled so that they operate only when needed, there can be appreciable savings of energy.

Exhaust air fans that remove odors or fumes should be scheduled to operate only when the odors or fumes are being produced. Examples are laboratory hoods and kitchen vents.

Exhaust fans used to remove excess heat build-up in certain spaces (such as storerooms and warehouses) should be controlled with thermostats so that they operate only when needed. Such fans may operate even in winter since excessive heat may be produced in certain locations.

In addition, dampers should be installed in the exhaust air discharge patch. This action would stop uncontrolled outside air from entering the heated space and prevent the loss of heated air when exhaust is not needed.

Estimate of Savings From Outside Air Control

The savings of energy from proper control of outdoor air requirements may be estimated from the following equation:

$$E = 0.0108 \times C \times P_o (T_i - T_o) \times H \times W$$

Equation 2

where:

E = Energy saved, in units of Btu per year.
C = Air capacity of the system, in cfm.
P_o = Percentage of outdoor air.
T_i = Average indoor temperature.
T_o = Average outdoor temperature.
H = Number of hours per week that the saving measure is in effect.
W = Number of weeks in the heating season.

As an example, consider the effect of reducing the ventilation during unoccupied periods in an office building in Chicago, where the average outdoor temperature is 34.2°F during the 30-week heating season. The building system has an air handling capacity of 60,000 cfm, 25% ventilation air is used, and damper leakage is 0.5%. The proper percentage P to use in the above equation is as follows:

$$P = 25 - 0.5 = 24.5 \qquad \text{Equation 3}$$

Assume that the average indoor temperature is 60°F during 118 hours per week when the building is unoccupied. Then the energy savings are the following:

$$\begin{aligned} E &= 0.0108 \times 60000 \times 24.5 \times (60 - 34.2) \\ &\quad \times 118 \times 30 \\ &= 1450 \times 10^{6} \text{ Btu per year.} \end{aligned}$$

At a fuel cost of \$3.87 per 10^6 Btu, this would amount to an annual savings of the following:

$$1450 \times 3.87 = \$5611.$$

This example shows dramatically how even relatively simple conservation measures can produce significant savings.

IMPROVED HEATING COIL OPERATION

The heating coils that heat the air can waste energy unless they are used effectively. There are several simple control measures that can be used to save energy by improving the operation of the heating coils, including the following:

- Reset of hot deck temperature
- Zone optimization

RESET OF HOT DECK TEMPERATURE

Resetting the hot deck temperature applies to dual-duct systems and multiple-zone systems. Many systems which use a hot deck and a cold deck use fixed temperatures for the decks. However, this does not take the actual heating needs into account. They may waste energy by mixing air that is unnecessarily hot with air that is uunnecessarily cold — which is especially true when heating demand is low. The heat that is needed could be produced with air of lower temperature.

Energy and money can be saved by having the control system respond to the zone that demands the most heat. The temperature of the hot deck should be set so that it is capable of handling just this demand. As the demand decreases, the temperature of the hot deck should be lowered, thereby reducing the energy that would be needed to heat the hot deck.

The reset of the hot deck temperature should be used in conjunction with a reset of the cold deck temperature.

The demand for heating from the different zones is analyzed from the output of the thermostat for each zone. The temperature of the hot deck is reset to satisfy that zone. Thus, the deck temperature responds to the load, rather than to a fixed schedule based on maximum possible demand. The lessened need for heated air and for a mixture of heated and cooled air saves energy.

ZONE OPTIMIZATION

Zone optimization is applicable to systems that use terminal reheat. These systems usually apply thermostatically controlled reheating in every zone to maintain comfort. If every zone is reheating, energy is being wasted. The heating needs from the zones can be analyzed, and the system can be adjusted as necessary. The demand from each zone is measured, and the temperature of the cold supply air is increased to minimize the amount of reheat energy.

This procedure – under the control of the building automation controller – makes the heating and ventilating system flexible. It satisfies the heating demand of the zone with the greatest needs; and, at the same time, it reduces the amount of energy needed for reheating.

ESTIMATE OF SAVINGS FROM IMPROVED HEATING COIL OPERATION

The annual energy savings from automated reset of the hot deck temperature during the heating season may be estimated from the following equation:

$$E = 0.0108 \times C \times P_h \times \Delta T_h \times H_o \times W$$

Equation 4

where:

E = Energy saved, in units of Btu per year.
C = Air capacity of the system, in cfm.
P_h = Percentage of the air that flows through the hot deck.
ΔT_h = Temperature reset of the hot deck, in °F.
H_o = Number of hours per week that the measure is in effect.
W = Number of weeks in the heating season.

For a school in Spokane, Washington, with a 35-week heating season, the air handling capacity of the heating system is 30,000 cfm, and 60% of the air flows through the hot deck. The school is occupied 60 hours per week, and the temperature of the hot deck is reset by an average of 2°F during this time.

The annual energy savings are the following:

$$E = 0.0108 \times 30000 \times 60 \times 2 \times 60 \times 35 = 81.6 \times 10^6 \text{ Btu/year.}$$

At a gas fuel cost of \$4 per 10^6 Btu, this saves 81.6 x \$4 = \$326.4 per year.

CONTROL OF FAN OPERATION

The fans that circulate air in the heating system are important candidates for automated control. If the fans are simply allowed to run all the time, significant amounts of energy may be wasted. Methods of controlling the operations of the fans include the following:

- Duty cycling of fans
- Equipment scheduling

DUTY CYCLING OF FANS

A duty cycle program saves energy by shutting off the fans for a part of their usual operational periods. This action may be controlled by the central computer. The program may simply turn off the fans for a fixed period at preset intervals. More sophisticated programming can take the space temperature and the outdoor temperature into account, and it can turn the fans off at variable intervals, depending on conditions. Building automation systems are well adapted to control the cycling of fans in heating and ventilation systems.

Not all fans systems are good candidates for duty cycling. In some cases, ventilation needs are critical and should not be interrrupted. Examples are a chemical operation, where fumes may be produced, or a hospital operating room.

EQUIPMENT SCHEDULING

Automatic scheduling of fans in heating and ventilating equipment saves energy in several ways: It reduces the amount of energy needed to heat the ventilating air, and it saves the electrical energy needed to drive the fans.

Energy savings are derived from establishing a weekly schedule. The equipment is turned on and off in accordance with the hours that the building is normally occupied. The start times should be set so that the morning warm-up time is no longer than necessary. This can be controlled by the outdoor temperature. On very cold days in winter, the warm-up time may have to be extended. On milder days, the warm-up period may be shortened.

Therefore, to achieve the largest energy savings, the scheduling must be flexible. This is especially true if there are changes in the occupancy patterns of the building. Fixed schedules must fit the longest periods of occupancy. Flexible scheduling can be changed rapidly to keep up with changing occupancy, and flexible scheduling can be done without equipment changes from a central computer control system.

INDIVIDUAL ROOM CONTROL

Energy savings are possible by properly controlling conditions in the space being heated. This section of the module discusses methods of conserving heating energy based on proper thermostat usage and air flow in the heated area. The thermostat is probably the most important part of an energy conservation program. The room thermostat also is the easiest place to begin an energy conservation program.

Several methods of applying this method of conservation include the following:

- Lowering thermostat setpoint
- Reducing temperature during unoccupied periods
- Separating heating and cooling setpoints
- Converting from constant-air-volume to variable-air volume

LOWERING THERMOSTAT SETPOINT

The thermostat should be lowered to 68°F (or even lower during the heating season). Savings result from maintaining the temperature of the heated space at a temperature which is compatible with new standards. The U.S. Government standard for public buildings is now 65°F, except for buildings that are granted an exception to the standard. (An example for which an exception might be appropriate is a hospital.)

Moreover, the control of the temperature of the heated space should not be accessible to the occupants of the space. All the energy savings can be lost by allowing the occupants free access to the thermostat adjustment. A thermostat that can be locked or one that is designed to prevent occupant adjustment should be used.

REDUCING TEMPERATURE DURING UNOCCUPIED PERIODS

During the heating season, the temperature of the heated areas should be set to a lower temperature at night or during unoccupied hours. Thermostats with separate setpoints for day and night operation (sometimes called clock thermostats) are used frequently. The changeover from high to low setting can be controlled by a time clock, or by the building automation system.

If the thermostats are not automated, the temperature setpoints can be changed manually. However, this may not be realistic for large buildings with many thermostats. In this case, clock thermostats or thermostats that can be automatically controlled should be used. The savings in energy would soon pay for the cost of changing the thermostats.

SEPARATING HEATING AND COOLING SETPOINTS

Some systems are capable of providing both heating and cooling on demand. It is obvious that heating and cooling should not be supplied simultaneously, but this can be avoided by separating the setpoints for heating and cooling. This procedure provides a so-called "zero energy band" of temperatures between the two setpoints. When the temperature is in this band, neither heating or cooling is required.

The following is an example: If the heating setpoint is 68°F and the cooling setpoint is 78°F at the same time that the temperature is in the zero energy band between 68°F and 78°F, then no energy will be saved.

CONVERTING FROM CONSTANT-AIR-VOLUME TO VARIABLE-AIR-VOLUME

Some buildings use a dual-duct system: one supplying hot air and one supplying cooled air. The air from the two ducts is mixed to produce the desired temperature. Thus, if heating is desired, more hot air and less cooled air is mixed in. The amount of mixed air delivered to the room is held constant, and the temperature of the air entering the room is controlled by the mixing.

The above procedure is wasteful. The energy that was expended to heat the hot air and the additional energy that was expended to cool the cold air are wasted when the air is mixed. Instead, space temperature can be controlled by changing the volume of air entering the space. Thus, if heating is desired, the volume of heated air entering the space is increased. When the temperature rises to its desired value, the flow of heated air is simply reduced. No cooled air is used.

The conversion from constant-air-volume to variable-air-volume is a simple procedure in most cases. The flow of the air in the two ducts is controlled by motorized dampers. These dampers can be placed under the control of a building automation system, which will control the dampers. Only one damper will be open at a time. This switch-over can be done with automated control, with a minimal need for replacement of equipment.

ESTIMATING SAVINGS FROM INDIVIDUAL ROOM CONTROL

The savings in energy from proper control of the temperature in heated areas may be estimated from the following equation:

$$E = F \times \Delta T \times H \times W \qquad \text{Equation 5}$$

where:

E = Energy savings, in Btu/year.

F = Factor defining the heat loss from a building heated to a temperature above the outdoor temperature.

ΔT = Amount by which the temperature is reduced in the heated area, in °F.

H = Number of hours per week that the temperature is reduced.

W = Length of the heating season, in weeks.

The factor, F, has units of Btu/hour/°F; and it varies from building to building, depending on the size and shape of the building, the insulation, the number of windows, the construction materials, and so forth. It is a measure of the rate at which heat escapes from the building to the colder outdoors.

For example, consider an office building constructed of 6" precast concrete panels that is 200' x 200' x 25' high, with 80,000 square feet of floor space. In this building, the value of F may be around 14,000 Btu/hr/°F. If this building were located in Madision, Wisconsin, where the heating season is 31-weeks long, consider the effect of reducing the thermostat from its constant 68°F setpoint during unoccupied periods. If the thermostat is at 68°F from 7 a.m. to 5 p.m. five days a week, and it is at 55°F at all other times during the winter, then, in the above equation, $\Delta T = 13°F$ and $H = 118$ hours per week. Then, the following may be written:

$$E = 14{,}000 \times 13 \times 118 \times 31 = 666 \times 10^6 \text{ Btu/year.}$$

At a cost of $\$4/10^6$ Btu for gas fuel, this would produce an annual savings of $2664.

EXERCISES

1. For an office building in Duluth, Minnesota, where the average outdoor temperature is 28°F during a 37-week-long heating season, estimate the annual energy savings produced by installing low leakage dampers in the 50,000 cfm air handling system. The dampers are supposed to be closed for 120 hours per week, but in their nominally closed condition they have a leakage of 10%. The low leakage dampers will reduce this to 0.6%. The average indoor temperature is 68°F.
2. A light industrial plant in Edmonton, Alberta, passes 70% of the air through the hot deck of a 100,000 cfm capacity dual-duct heating, ventilating, and air conditioning system. The hot deck temperature is reset by an automatic controller by an average of 1.5°F for 48 hours per week during a heating season that lasts 38 weeks. If the cost of the oil fuel is $\$6.00/10^6$ Btu, how much money will be saved per year?
3. A factory in Atlanta, Georgia, where the heating season is 20-weeks long, is occupied for 60 hours a week and unoccupied for 108 hours per week. The factory has a heat loss factor F of 22,500 Btu/hr/°F. The thermostat setpoint is now at 74°F. Calculate the energy savings that would result from turning the thermostat down to 68°F during the occupied time and to 60°F during the unoccupied time.
4. Suppose a school building that burns #2 fuel oil in its furnace uses 10^6 Btu/hr. The stack gas temperature is 875°F, and the O_2 concentration is 12%. The boiler room temperature is 75°F. How much energy can be saved each hour by reducing the stack gas temperature to 475°F and the O_2 concentration to 4%? At $6.75/10 Btu, how much money can be saved for each hour of furnace operation?

5. List, describe, and explain conservation measures related to the following:
   - Improved furnace operation
   - Control of outdoor air
   - Improved heating coil operation
   - Control of fan operation
   - Individual room control

LABORATORY MATERIALS

Portable analyzer for flue gas temperature and gas composition
A strip chart recorder

LABORATORY PROCEDURES

In these procedures, the student will perform measurements and analyses on the heating system of a particular building. A commercial building's heating system would be more desirable to analyze than that of a private home. The school at which the course is being presented may allow the students, under proper supervision, to analyze the heating system of the school. If no other building is available for analysis, the home of the student may be used.

The student will first prepare an energy survey for the building. Then the student will determine whether the heating system is properly sized. Finally, the student will analyze the flue gas temperature and composition and will determine the efficiency of the heating system. Use the Data Table to record information.

The equipment needed is a portable analyzer for flue gas temperature and gas composition, and a strip chart recorder.

1. The Energy Survey

First perform an energy survey for the selected building, using the Data Table that follows. Fill in the information about the heating equipment and schedules, and the heating checklist in the sections provided in the Data Table.

Fill in the blanks as completely as possible and do not be concerned about having difficulties finding any information. Valuable information can be obtained from the physical plant administrator or the maintainence personnel.

After completing the Data Tables, analyze the information and make suggestions about how energy could be saved in the heating of the particular building.

2. Determination of Heating System Sizing

In this section of the laboratory, the student will determine whether the heating system is properly sized. This will be done by measuring the fraction of the time that the furnace is ON during a period of several days.

Attach the leads of the chart recorder to the power source for the furnace's blower motor. Turn the chart recorder on. Check to see that the recorder is running at a slow rate of paper feed and that it has enough paper. Let it record the presence of voltage on the blower motor over a period of several days (preferably, at least three). This must be done at a time of the year when the furnace is providing heat.

After the recording period, use the chart record to determine how long the furnace was ON during the recording period. Determine then the fraction, F_1, of the time that the furnace was ON.

From local weather records, determine the minimum outdoor temperature, T_{min}, ever recorded in the area, as well as the number of heating degree days, N_d, during the recording period. This information is sometimes published in local newpapers, or it is available from the weather service. Determine the fraction, F_2, given by the following equation:

$$F_2 = \frac{N_d}{D \times (65 - T_{min})} \qquad \text{Equation 6}$$

where:

D = Number of days in the recording period. This is the fraction of the time that the furnace should be ON.

If F_1 is approximately equal to F_2, the furnace is properly sized. If F_1 is much less than F_2, the furnace is cycling on and off too often, and is oversized.

3. Measurement of Flue Gas

Use the portable flue gas analyzer. Insert the sensor head of the analyzer into the flue of the furnace when the furnace has been ON for several minutes and is well warmed up. From the information on the meters, record the readings for O_2 concentration and flue gas temperature. (If the meter reads CO_2 concentration, record that value and then use Figure 10 to find the O_2 concentration.)

Use the values obtained from this measurement to determine the system efficiency. Use either Figure 11 or Figure 12, depending on the fuel used. (Remember that the flue temperature rise is the measured temperature minus the ambient temperature in the boiler room.)

How might the efficiency of this system be improved?

DATA TABLE

HEATING ENERGY SURVEY FORM

HEATING EQUIPMENT AND SCHEDULES

SIZE, GROSS SQ FT

AREA HEATED

TYPE(S) OF OCCUPANCY: (% OR SQ FT)

Office____________________ (Other)____________

Warehouse__________________ (Other)____________

Manufacturing______________ (Other)____________

Retail____________________

Lobbies & Mall______________
(Enclosed)

BUILDING USE AND OCCUPANCY

Fully Occupied: (50% or more of normal)

Weekdays (Hours)____________to__________

Weekends (Hours)____________to__________

____________to__________ Sunday

____________to__________ Holidays

Remarks: Describe below if occupancy differs for different floors, areas, buildings:____________________

____

____

Data Table. Continued.

Heating Checklist for Control System Upgrade

Yes No

DAY OPERATION

☐ ☐ 1. Are thermostats set at 68-70°F or less in public spaces?

☐ ☐ Locked?

☐ ☐ 2. If they are non-locking, is there any provision to keep settings at 68-70°F?

☐ ☐ 3. Does the thermostat work? When set below 68°F, does valve, damper, or heat source turn on?

☐ ☐ 4. Is thermostat calibrated within 1 to 2°F of setting?

☐ ☐ 5. When set below 68°F, is the cooling source (outside air or refrigeration) locked out?

☐ ☐ 6. Is ZEB (Zero Energy Band) operation provided for?

☐ ☐ 7. Have you reduced outdoor air ventilating quantity when the building is occupied, consistent with standards? (5-10 CFM/person for office areas.)

☐ ☐ 8. Do you shut off exhaust fans in toilets, kitchens, or labs when areas served are unoccupied?

NIGHT/UNOCCUPIED OPERATION

☐ ☐ 9. When unoccupied, is the temperature setting automatically reduced by at least 10°F?

☐ ☐ 10. Are warehouses or storage areas kept at lower temperatures than occupied areas?

☐ ☐ 11. Do you close outdoor air damper when the building is unoccupied?

☐ ☐ 12. Do outdoor air dampers close tightly during night or unoccupied times?

Data Table. Continued.

Heating **Checklist for Control System Upgrade**

Yes No

STEAM, HOT WATER, OR ELECTRICAL SYSTEMS FOR SPACE-HEATING

☐ ☐ 13. **Have you determined above what outdoor temperature you can shut off heating boilers, heat exchanger pumps and/or electric heat?**

☐ ☐ 14. **If 13 differs for different buildings, or zones, or times of day, have these parameters been determined?**

☐ ☐ 15. **Do you have procedures in effect to shut off the heat, as determined under 13 and 14?**

☐ ☐ 16. **For space-heating hot water systems, have you checked to see if water temperatures or temperature schedules are at or below original design? (Remember that original design temperatures for secondary hot water were based on a 75°F room temperature requirement.)**

REFERENCES

ASHRAE. *Handbook and Product Directory Equipment*. Chapters 1 and 3. New York: NY: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1975.

Baron, S.L. *Manual of Energy Saving in Existing Buildings and Plants*, Vol. II. *Facility Modifications*. Chapters 2 and 4. Englewood Cliffs, NJ: Prentice-Hall, Inc. 1978.

Bonne, V.; Patani, A.; Lestie, C.; and DeWerth, D.W. Dynamic Computer and Laboratory Simulations of Gas Fired Central Heating and Systems. Montreux, Switzerland: Proceedings of International Symposium on Simulation Modeling and Decision in Energy Systems. June 19-21, 1979.

Dublin, F.S.; Mindell, H.L.; and Bloome, S. How to Save Energy and Cut Costs in Existing Industrial and Commercial Buildings. Chapters 4, 7, 13, and 17. Park Ridge, NJ: Noyes Data Corp., 1976.

Energy Conservation with Comfort. 2nd ed. Minneapolis, MN: Honeywell, Inc., 1979.

TEST

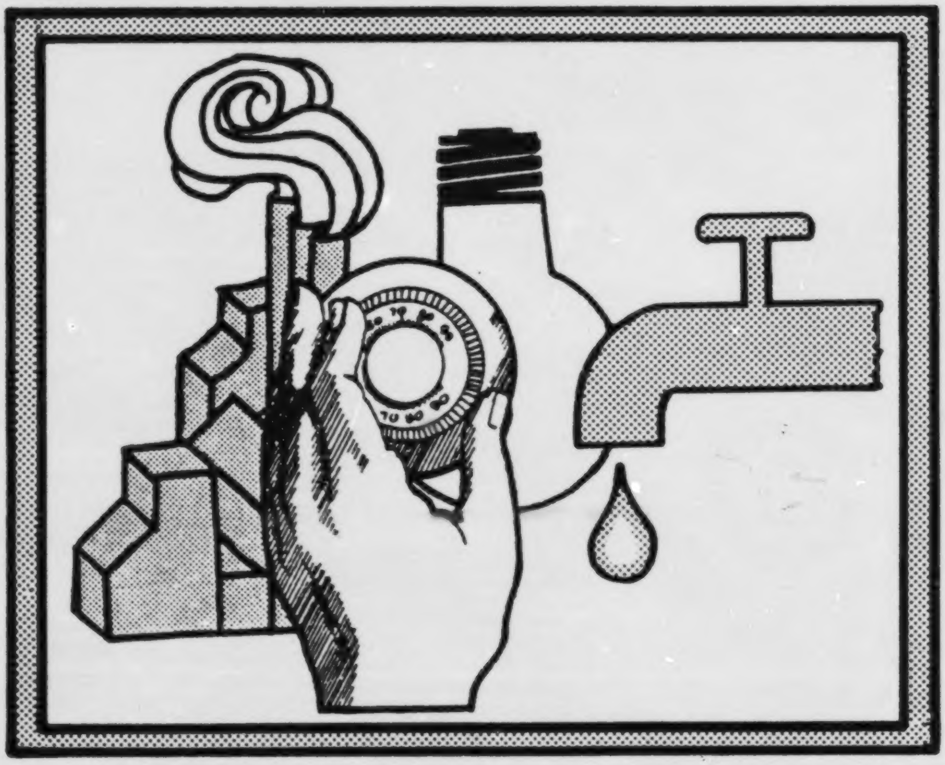
Fill in the blanks.

1. Conservation methods related to improving furnace operation include improvement of __________ efficiency, ___________ of heat losses, proper ________ of heating system, and flue gas ________.
2. Conservation methods related to outdoor air control include _________ minimum outdoor air, low leakage ______, reduction of ventilation during __________ _______, and control of _________ air.
3. Conservation measures related to improved heating control include reset of ___ ____ temperature and ______ optimization.
4. Conservation measures related to control of fans include ____ _______ of fans and equipment __________.
5. Conservation measurements related to individual room control include lowering thermostat ___ _____, ________ _________ during unoccupied periods, _________ heating and cooling setpoints, and conversion from constant air volume to ________ ___ ______.
6. A properly adjusted furnace will have O_2 concentration in the range __ to __ % in the flue gas.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-03

CONSERVATION PRINCIPLES AND EFFICIENCY MEASUREMENTS - SPACE COOLING

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module deals with the conservation of energy in space cooling systems. The student studies practical techniques for saving energy in building cooling systems, as well as measurement and analysis techniques. In the laboratory, the student conducts an energy survey relative to cooling requirements.

Emphasis is placed on cooling control practices and energy conservation practices related to system modification. Thus, like Module EC-01, this module describes relatively inexpensive measures that can be taken rather than major structural changes to the building. The more major issues related to building design and construction will be discussed in Module EC-07. The major thrust of this module involves the minor system modifications that pay for themselves in a short period of time, and changes in control and scheduling that reduce energy waste.

The easiest way to reduce cooling costs, of course, is to raise the cooling thermostat. This measure requires no investment and makes an immediate impact. The current mandate from the federal government stipulates that cooling thermostats in public buildings be set no lower than 78°F.

The emphasis in this module is on larger buildings – apartment buildings, schools, offices, factories, and so forth – since they have larger and more elaborate cooling systems than private homes. The possibilities for energy conservation through improved control are greater in such systems. Some of the measures discussed will, of course, be applicable to private homes.

The descriptions in this module refer to space cooling rather than air conditioning since the term "air conditioning" is often used loosely to mean just cooling. Yet, properly defined, air conditioning means the control of a number of quantities related to the air in an enclosed space – such as control of air temperature, humidity, and cleanliness. This module emphasizes issues related primarily to the cooling of air.

PREREQUISITES

The student should have a basic understanding of algebra and physics and should have completed Modules EC-01 and EC-02 of Energy Conservation.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List, describe, and explain conservation measures related to the following:
    a. Control of chiller operation.
    b. Reduction of building heat load.
    c. Use of outdoor air for cooling.
    d. Control of the cooling coils.
    e. Control of the fans.
    f. Individual room control.
2. Perform calculations related to savings of cooling energy for the following:
    a. Use of outdoor air for cooling.
    b. Control of the cooling coils.

    c. Control of the fans.
    d. Individual room control.
3. Prepare an energy survey for cooling in a particular building.
4. For a particular building, measure the refrigeration effect and the coefficient of performance of the cooling system.
5. Define terms associated with cooling and air conditioning, including the following:
    a. Wet-bulb temperature.
    b. Dry-bulb temperature.
    c. Hygrometer.
    d. Psychrometric chart.
    e. Relative humidity.
    f. Coefficient of performance.

FUNDAMENTAL CONSIDERATIONS OF SPACE COOLING

Space cooling is used most often to improve human comfort during the warm parts of the year. Space cooling also serves other purposes, such as to preserve food or to provide a proper environment for temperature-sensitive manufacturing processes.

HUMIDITY

Water vapor (humidity) in the atmosphere is an important factor to consider in regard to human comfort during the cooling season. Humidity is less important in heating applications. One reason is that the water vapor content of air in many of the colder sections of the United States is low. For space heating applications, air temperature is simply raised to the desired temperature without regard to the water vapor content. But for space cooling applications, humidity is an important issue – which the following discussion will explain.

The absolute humidity is defined as "the amount of water vapor present in a given amount of air." It may be expressed in different units: for example, as grams of water vapor per cubic meter of air, or pounds of water vapor per pound of air.

There is a maximum amount of water vapor that can be present in the air at any given temperature. This amount is shown in Figure 1, which shows the saturated pressure of water vapor in air versus temperature. When the amount of water vapor is equal to the maximum value, the air is said to be saturated. The amount of water that the air can hold is very low at low temperatures – characteristic of winter conditions. However, the amount increases rapidly at elevated temperatures. (Note that the normal pressure of air at sea level is about 760 mm Hg).

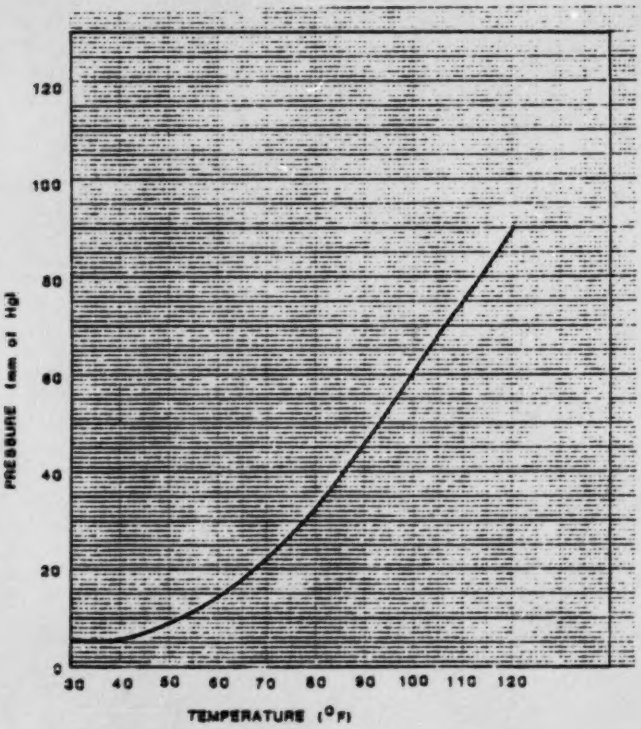


Figure 1. Saturated Pressure of Water Vapor in Air Vs. Temperature.

The amount of water vapor in the air is usually less than the saturated value. The ratio of the actual amount of water vapor to the saturated amount is called the relative humidity. The relative humidity is expressed as a percentage.

For example, at a temperature of 85°F, the saturated vapor pressure of water vapor is 31 mm Hg. If the actual vapor pressure of water is 18.6 mm Hg, the relative humidity is 60% (18.6 ÷ 31 = 0.60).

The relative humidity changes as temperature changes. Thus, if outdoor air at 32°F and 50% relative humidity (vapor pressure 2 mm Hg of water vapor) is raised to 70°F, the relative humidity drops, even though the absolute humidity stays the same. Since the saturated vapor pressure at 70°F is 19 mm Hg, the relative humidity will be 2/19 = 10.5%. Even though no water vapor has been removed, the relative humidity has been greatly decreased in the heating. As a result, the relative humidity of indoor air in the winter in the northern parts of the United States is usually very low. Sometimes, for improved comfort, extra humidity will be added to indoor air in the winter.

For space cooling, humidity often must be removed. If the outdoor air has high relative humidity, the relative humidity will increase as the air is cooled. The humidity will eventually reach 100%, and moisture will begin to condense out of the air. Surfaces — especially cool surfaces like water pipes — will become covered with droplets of water. In addition, fog could begin to form.

Dew Point

The temperature at which water begins to condense out of the air is called the dew point. The dew point depends on both the initial air temperature and the relative humidity.

EXAMPLE A: CALCULATION OF DEW POINT.	
Given:	The temperature is 100°F and the relative humidity is 50%.
Find:	The dew point.
Solution:	From Figure 1, the saturated vapor pressure of water vapor at 100°F is 49 mm Hg. At 50% relative humidity, the air would contain 24.5 mm Hg of water vapor. If the figure is read horizontally, it can be seen that 24.5 mm Hg of water vapor is saturated at 78°F. This is the dew point for the stated initial conditions.

High values of relative humidity and high temperatures lead to discomfort. The human body, under conditions of high temperature, tries to cool itself with perspiration. Perspiration will evaporate less under conditions of high relative humidity, and the body's temperature regulation will be less effective. The result is discomfort.

Thus, space cooling is often accompanied by dehumidification of the air. The reasons are twofold:

- To reduce the relative humidity and improve comfort
- To minimize condensation of water vapor out of the air

Hygrometer

The relative humidity is measured with a device called a hygrometer. There are various principles used in hygrometer construction. One common method is the use of two thermometers. One is an ordinary glass thermometer, called a dry bulb. The other thermometer, called a wet bulb, is covered with a piece of cloth that is saturated with distilled water. The two bulbs are ventilated with air. The wet bulb will indicate a lower temperature because of cooling by evaporation of the water. Together, the two temperatures give a measure of the relative humidity.

The terms "wet-bulb temperature" and "dry-bulb temperature" are common terms. The dry-bulb temperature is the temperature measured by an ordinary thermometer. If the term "air temperature" is used without qualification, it means the dry-bulb temperature. The wet-bulb temperature is the temperature measured by a thermometer that has a moist cloth jacket and is suitably ventilated. The wet-bulb temperature is always equal to or lower than the dry-bulb temperature. At low relative humidity, the wet-bulb temperature will be considerably lower than the dry-bulb temperature. At high relative humidity, there will be less evaporative cooling of the wet bulb, and the two temperatures will be close together. At 100% relative humidity, the temperatures will be equal.

One common construction of a hygrometer that uses both wet and dry bulbs is the sling hygrometer. The sling hygrometer has the two bulbs mounted on a frame that is connected to a handle by means of a bearing. To ventilate the bulbs, the device is whirled by hand.

There are several varieties of hygrometers. One type uses strands of human hair that expand with increasing relative humidity. The expansion is used to drive a pointer that indicates the relative humidity.

Psychrometric Chart

The values of the wet-and dry-bulb temperatures may be used to find the relative humidity and other quantities by means of a psychrometric chart. A psychrometric chart is a chart constructed to provide convenient determination of the properties of air-water vapor mixtures based on measurement of wet- and dry-bulb temperatures. An example of a psychrometric chart is shown in Figure 2.

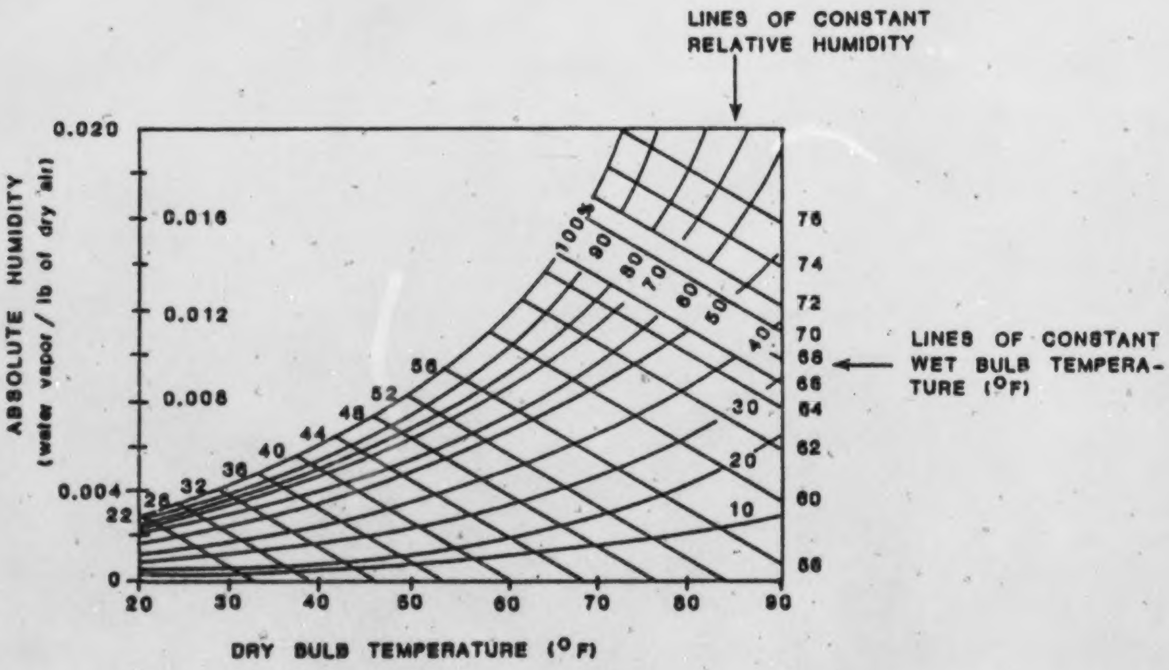


Figure 2. Psychrometric Chart.

There are different psychrometric charts available, each one designed in a format for a specific value of atmospheric pressure. Three common types of psychromatric charts are the following: for sea level atmospheric pressure, for 5000-foot elevation atmospheric pressure, and for 7500-foot elevation atmospheric pressure. The chart in Figure 2 is for sea level air pressure.

EXAMPLE B: CALCULATION OF ABSOLUTE AND RELATIVE HUMIDITY.

Given: A dry-bulb temperature of 70°F and a wet-bulb temperature of 62°F.

Find: The absolute humidity and the relative humidity.

Solution: Using the psychrometric chart, read upwards from the dry-bulb temperature of 70°F to the wet-bulb line corresponding to 62°F. These intersect along the relative humidity curve corresponding to 60%. Reading horizontally to the left hand scale from this intersection gives an absolute humidity of 0.0115 lb water vapor/lb dry air.

The psychrometric chart may be used to relate air conditions to sensations of human comfort. Figure 3 shows a simplified psychrometric chart with dashed lines showing three regions of subjective comfort levels. The area around the leftmost dashed line is the condition perceived by most people as being comfortable. (The sensations of comfort felt within this range apply for lightly clothed, sedentary individuals. The sensations will, of course, vary as clothing

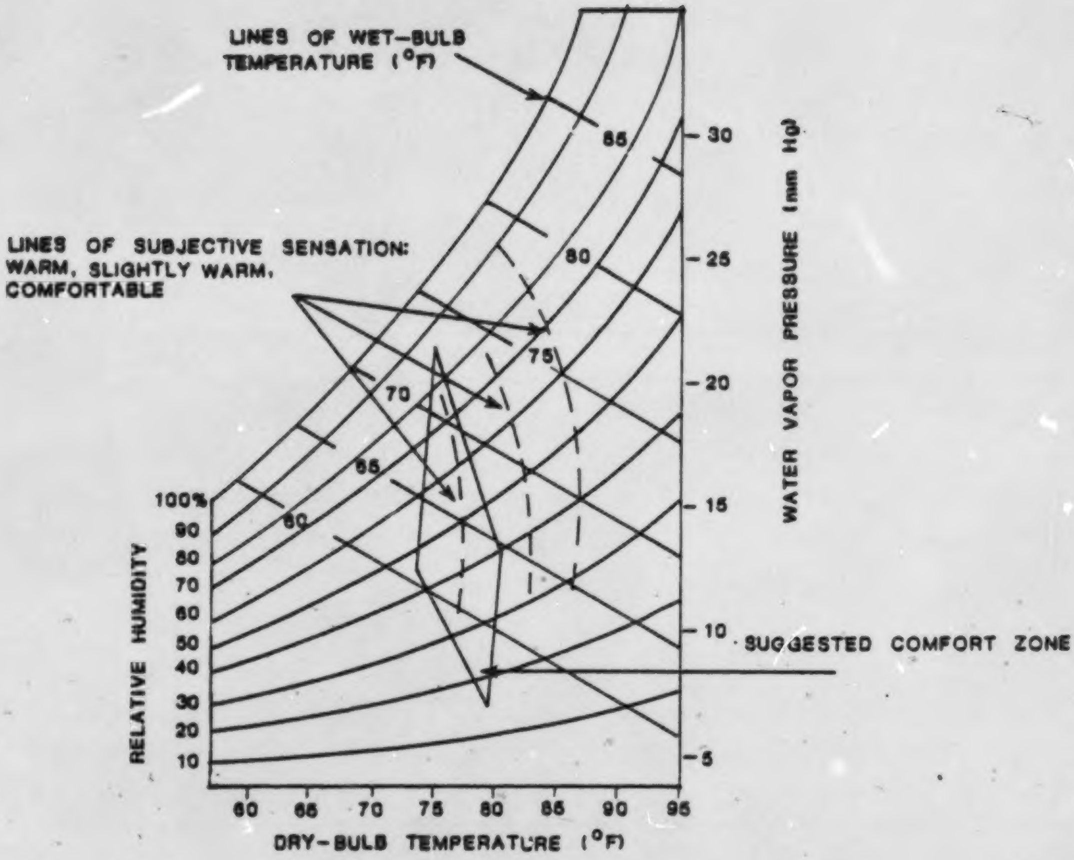


Figure 3. Psychrometric Chart Showing Comfort Levels.

and level of activity change.) The center dashed line corresponds to conditions perceived as slightly warm, and the right dashed line corresponds to conditions considered warm by most people. Notice that the chart shows that people require lower temperatures for comfort as the relative humidity rises. At low relative humidity (less than 50%), a temperature of 77.5°F is perceived as comfortable. As relative humidity rises to 80%, the temperature at which people feel comfortable falls to 75°F. The diamond-shaped area bounded by solid lines represents a comfort zone suggested by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). It may be noted that the current federal standards for public buildings require a minimum cooling temperature of 78°F, without regard for the relative humidity.

TOTAL HEAT CONTENT

An important quantity in air conditioning is the total heat content of the air. The total heat content, including the contribution due to water vapor in the air, is called the enthalpy. Air with a high moisture content has higher enthalpy than dry air at the same temperature, and it will place a greater load on the cooling system. The enthalpy is measured in units of Btu per pound of dry air. In air conditioning, dry air at 0°F is considered to have zero enthalpy; and values of enthalpy used in air conditioning are referenced to this condition as zero. Values of enthalpy may also be determined from a psychrometric chart. Figure 4 shows a simplified psychrometric chart giving enthalpy values. The lines running at an angle across the chart represent conditions of constant enthalpy. Note that for constant dry-bulb temperature, the enthalpy increases with moisture content.

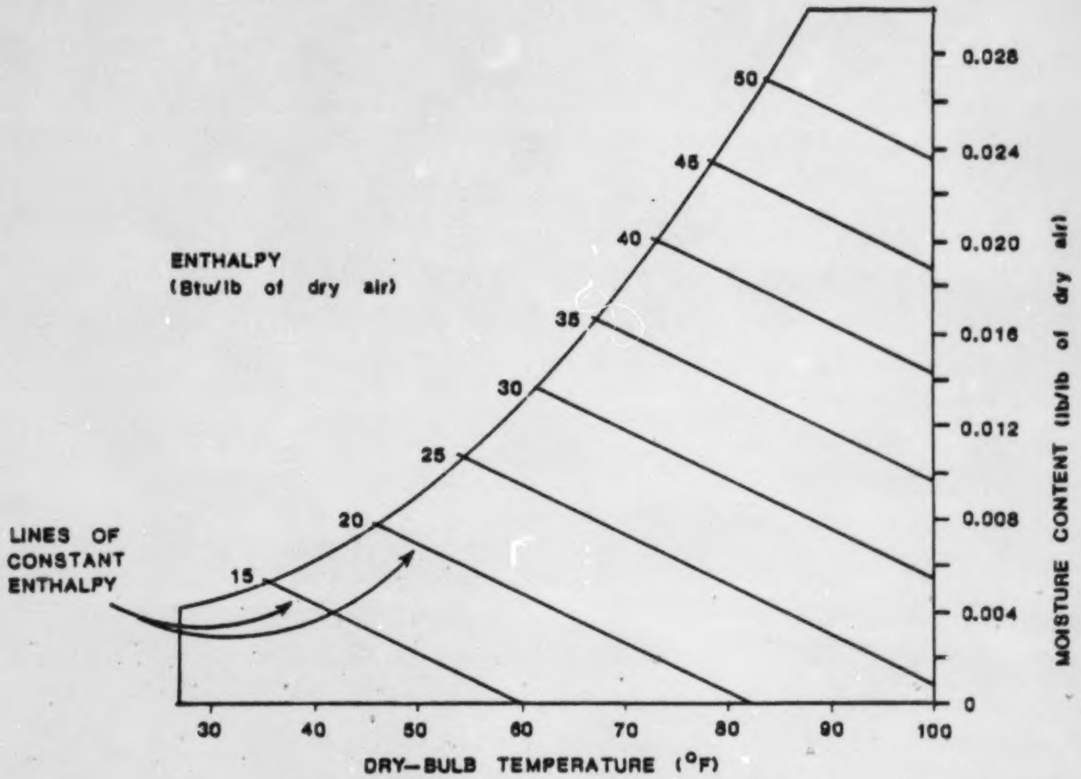


Figure 4. Psychromatric Chart Showing Enthalpy.

EXAMPLE C: CALCULATION OF ENTHALPY.

Given: The dry-bulb temperature is 65°F and the moisture content is 0.004 pounds per pound of dry air.

Find: The enthalpy.

Example C. Continued.

Solution: On Figure 4, read horizontally from 0.004 pounds moisture content, and vertically from 65°F. These two lines intersect along the line corresponding to an enthalpy of 20 Btu/lb dry air.

REFRIGERANTS

Cooling for air conditioning purposes is produced by a fluid subjected to a refrigeration cycle. A refrigeration cycle is defined as "a series of thermodynamic processes in which heat is withdrawn from a cold body and expelled to a hot body." Some working fluid, called the refrigerant, is compressed, cooled, and then expanded. As it expands, the refrigerant absorbs heat from its surroundings to provide cooling. The compression part of the cycle raises the temperature of the refrigerant above that of its surroundings. It gives up its heat in a heat exchanger, outside the space which is to be cooled. Then, expansion lowers the temperature of the refrigerant below the temperature of the space to be cooled. The cooled refrigerant then gains heat in a heat exchanger – inside the space to be cooled – and produces cooling within the desired space.

A schematic diagram of a basic refrigeration cycle is shown in Figure 5. This shows the basic components for the cycle: a compressor, a condenser, an expansion valve, and an evaporator. The refrigerant in vapor form at point 1 is compressed in the compressor. Mechanical work is expended by the compressor to produce a high temperature, high pressure vapor at point 2. In the condenser, the vapor cools by heat exchange with its surroundings; then it leaves the condenser as a liquid at high pressure (point 3). The vapor then expands through a valve, and leaves the valve as a low pressure, low temperature vapor (point 4). At this time, the vapor absorbs heat in the evaporator, producing the desired cooling in the surroundings. The fluid is then ready for another cycle.

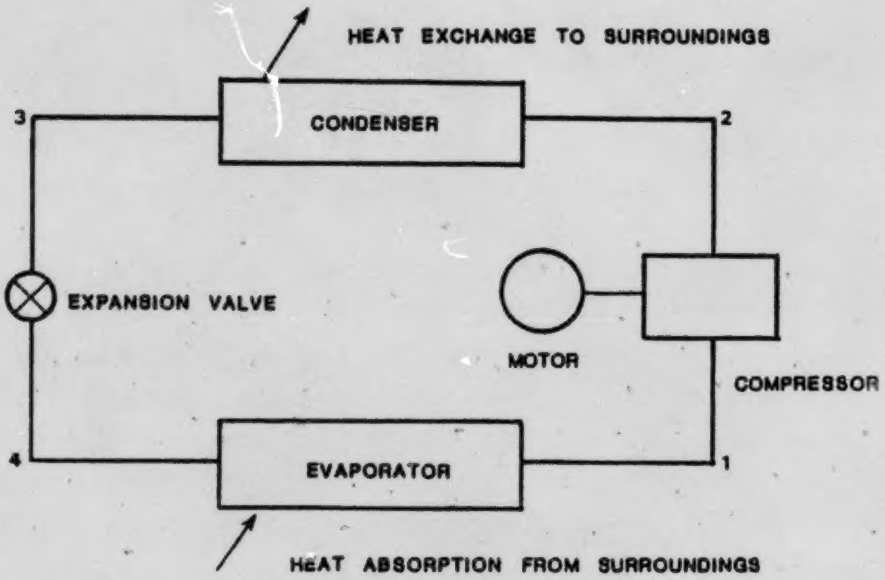

HEAT EXCHANGE TO SURROUNDINGS
3
CONDENSER
2
EXPANSION VALVE
MOTOR
COMPRESSOR
4
EVAPORATOR
1
HEAT ABSORPTION FROM SURROUNDINGS

Figure 5. Schematic Diagram of Basic Refrigeration Cycle.

A number of different fluids are used as refrigerants. Ammonia (NH_3) is used in some systems. Fluorocarbon compounds (commonly called Freons) are also widely used. An example is Freon-12, which has the chemical formula CCl_2F_2.

The Freons have the advantage of being nontoxic as compared to ammonia. Ammonia has a higher refrigerating effect (that is, it removes more Btus per pound of refrigerant) and, thus, is used in many large systems.

The cooling system incorporating this refrigeration cycle is often called a chiller when it is applied to air conditioning systems.

Figure 6 shows how the pressure and enthalpy vary during the different parts of the refrigeration cycle. The numbers 1-4 correspond to the points 1-4 in the diagram of Figure 5.

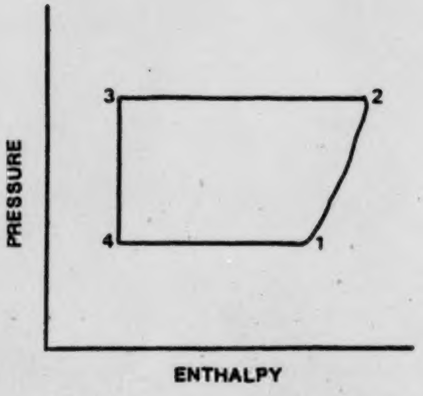


Figure 6. Schematic Diagram of Thermodynamic Properties During Refrigeration Cycle.

COEFFICIENT OF PERFORMANCE

The coefficient of performance (COP) is often used to compare the performance of cooling systems. COP is defined as "the amount of refrigeration produced, divided by the amount of input work required to produce it." Thus, COP may be written as follows:

$$COP = \frac{\text{Refrigeration effect}}{\text{Net work input}} \qquad \text{Equation 1}$$

COP is also related to the enthalpies at various points in the refrigeration cycle by the following equation:

$$COP = \frac{(h_1 - h_4)}{(h_2 - h_1)} \qquad \text{Equation 2}$$

where:

h_1, h_2, and h_4 = The values of the enthalpy at points 1, 2, and 4 in the refrigeration cycle, where the points are as denoted in Figures 5 and 6.

The COP, as defined in Equation 1, is essentially the efficiency of the cooling system. For measurement of the COP, technicians usually measure quantities related to the amount of cooling produced per unit of input energy, rather than measuring the enthalpies of the refrigerant in the refrigeration cycle. Thus, practical determination of COP involves use of Equation 1, rather than Equation 2.

The input is generally calculated from the electrical input to the cooling system. This is given by the following equation:

$$\text{Input} = \frac{\sqrt{3} \times V \times A \times PF}{1000} \qquad \text{Equation 3}$$

where:

Input = Input, in kilowatts (kW).
V = The voltage.
A = The number of amperes flowing (per phase of the electrical input).
PF = The power factor.

When the voltage and current in the alternating current system are in phase, the power factor will be equal to one (1). In practice, the voltage and current will be somewhat out of phase, and the power factor will be less than one. This condition will be described in more detail in Module EC-06.

COOLING EFFECT MEASUREMENTS

The cooling effect may be determined by measurements at several points in the system. For example, the enthalpy of the refrigerant in the cooling cycle could be measured; however, this is rarely done. The measurement of cooling effect is usually done by measuring the change in temperature of the air in the building as it flows past the cooling coils. Both the wet- and dry-bulb temperatures must be measured because of the possibility of condensation of moisture on the coil. Then the cooling effect may be determined by the following equation:

$$\text{Effect} = 60(h_u - h_d) \times C \times D \qquad \text{Equation 4}$$

where:

Effect = Cooling effect, expressed in Btu/hr.

h_u = Enthalpy upstream of the cooling coil, in Btu/lb.

h_d = Enthalpy downstream of the cooling coil, in Btu/lb.

C = Air capacity of the system, in ft^3/min.

D = Density of air.

The density of air is usually taken as 0.075 lb/ft^3. Variations of this value occur with barometric pressure and temperature, but use of the value given above will not introduce a significant error.

The enthalpies are determined by taking measurements of the wet- and dry-bulb temperatures upstream and then using a psychrometric chart, such as the one shown in Figure 7.

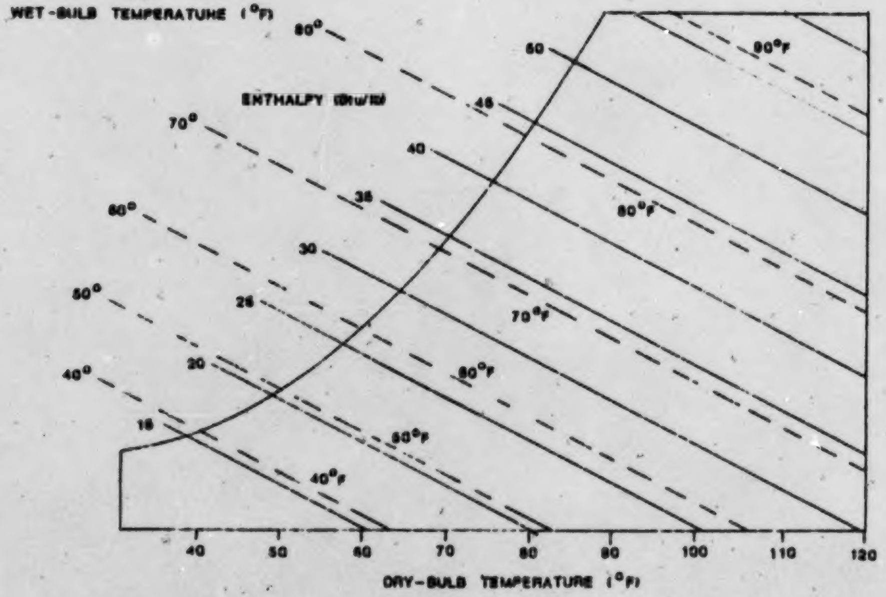


Figure 7. Psychrometric Chart for Enthalpy From Wet- and Dry-Bulb Temperatures.

In this figure, the solid lines are lines of constant enthalpy and the dashed lines are lines of constant wet-bulb temperature.

At times, the capacity of the air system is simply taken as the rated capacity given by the manufacturer. For more accurate determinations, the cross-sectional area of the duct and the velocity of the air flow can be measured. Devices to measure the velocity of the air flow are called anemometers. One type of anemometer uses a hot wire. The rate of heat transferred from the hot wire is a measure of air speed. The speed of the air flow is determined from either the electrical current needed to keep the wire at a constant temperature or from the electrical resistance of the wire when the current is kept constant.

This method of measuring the cooling effect from measurements of the temperature of the air and its velocity is the most common. Another method sometimes used requires instrumentation to measure the flow and temperature of the cooled water in the coils. The cooling effect (in Btu/hr) is given by the following equation:

$$\text{Effect} = 500 \times F \times (T_i - T_o) \qquad \text{Equation 5}$$

where:

F = Water flow.
T_i = Temperature of the water flowing into the chiller.
T_o = Temperature of the water flowing out of the chiller.

This method of determining the cooling effect is easier and probably more accurate than the measurements of air flow and temperature. However, in many cases, the needed instrumentation is not available.

Notice that the cooling effect is generally expressed in Btu/hr, whereas the electrical input is usually expressed in kilowatts (kW). To determine the COP, consistent units must be used. This can be done with the aid of these conversion factors:

$$1 \text{ Btu/hr} = 2.93 \times 10^{-4} \text{ kW}$$
$$1 \text{ kW} = 3{,}413 \text{ Btu/hr}$$

Another unit for cooling capacity is the ton. Although the ton has no basis in the fundamentals of air conditioning, it is often encountered in practical use. One ton of cooling is defined as "12,000 Btu/hr."

EXAMPLE D: DETERMINATION OF COP.

Given: In a building with 50,000 cfm air capacity, one measures wet-bulb temperatures and dry-bulb temperatures of 65°F and 90°F (respectively), upstream of the cooling coil, and 50°F and 78°F (respectively), downstream of the cooling coil. The electrical input is 1,200 amperes per phase at a voltage of 460 volts and a power factor of 0.9.

Find: The coefficient of performance.

Example D. Continued.

Solution: The electrical input is, from Equation 3,

$$\frac{\sqrt{3} \times 460 \times 1{,}200 \times 0.9}{1{,}000} = 860 \text{ kilowatts.}$$

From Figure 7, the enthalpies upstream and downstream of the cooling coil are (respectively) 30 and 20.5 Btu/lb. The cooling effect, from Equation 4 is the following:

$$60 \times (30 - 20.5) \times 50{,}000 \times 0.075 = 2.14 \times 10^6 \text{ Btu/hr}$$

$$= 627 \text{ kW.}$$

From Equation 1, the COP is as follows:

$$\frac{627}{860} = 0.729.$$

STRUCTURE OF COOLING SYSTEMS

The types of equipment used in cooling systems vary from system to system, and many different models and designs are available.

Two common types of compressors are the reciprocating compressor and the centrifugal compressor. Reciprocating compressors – the more popular type – use pistons driven from a crankshaft through a connecting rod. The refrigerant enters and leaves the cylinder through valves. The operation is somewhat similar to that of an automobile engine. Reciprocating compressors range in capacity from less than one ton (12,000 Btu/hr) to more than 100 tons.

Centrifugal compressors rely on rotating mechanical elements to continuously drive the fluid through the compressor.

In operation, they are more like a fan or a turbine. Centrifugal compressors, sometimes called turbocompressors, tend to be used in large capacity units with 75 tons capacity or greater.

Numerous types of condensers are also available — the most common of which is the so-called shell and tube type. This type of condenser consists of many individual stainless steel tubes (with diameters of approximately 1.5 inch) contained within a large circular shell. The number of tubes in one shell may range from 50 to more than 1,000. The condenser may be arranged so that the tubes are either horizontal or vertical.

The expansion valve provides for cooling of the refrigerant as it expands from a high pressure region to a low pressure region. The valve controls the flow of refrigerant through the evaporator. One common form of control uses a thermostat that monitors the temperature of the gas leaving the evaporator. If the gas temperature is too high, the thermostat opens the valve and increases the flow. The valve itself is often a needle valve. A cone-shaped point on the needle restricts the flow of refrigerant through a small orifice. The orifice will have a cone-shaped seat to match the shape of the needle point.

The evaporators, in which the refrigerant evaporates in the low pressure portion of the refrigeration cycle, can be similar in construction and appearance to the condensers. Many are also the shell and tube type.

The refrigeration cycle — which is carried out through these components — leads to a cold refrigerant in the central chiller. The cold refrigerant is then used in a heat exchanger to cool either air or water for the actual cooling of the building. There are three basic arrangements: all-air, all-water, and air-water.

In an all-air system, the building air is passed through the chiller and cooled by heat exchange with the refrigerant. The air is then passed through ducts to the space that is to be cooled. The all-air systems were the first air cooling systems developed. However, air has a low heat capacity; therefore, in order to provide a working fluid with the capability for carrying larger quantities of heat in small pipes, water is now often used. Water is cooled in the chiller and then circulated to a point near the space to be cooled. Then the air is cooled by heat exchange at the cooling coils.

In all-water systems, the chilled water is piped to coils in each space, and room air passes over the coils. In an air-water system, both air and water are distributed to each space that is to be cooled. The air is cooled somewhat and circulated through ducts. Chilled water is delivered to the cooling coils, which provide the final cooling to the desired temperature.

The system arrangements are similar to those already described in Module EC-02. For completeness, however, they will be reviewed briefly in the following paragraphs.

Figure 8 shows a single-zone system, analogous to single-zone heating systems. All the air is cooled by heat exchange with the water in the cooling coil at one location. The portion of the duct containing the chiller water coil is called the cold deck.

Figure 9 shows a terminal reheat system. A fixed cold air temperature is supplied by the cold deck. Air is reheated in the terminal units when the cooling load is less than maximum. Such systems can waste energy if too much cooling and reheating is required.

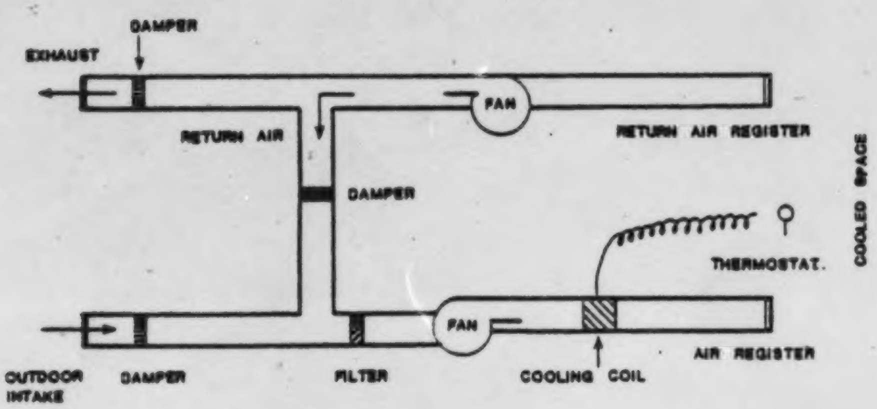

DAMPER
EXHAUST
FAN
RETURN AIR
RETURN AIR REGISTER
DAMPER
COOLED SPACE
THERMOSTAT.
FAN
AIR REGISTER
OUTDOOR INTAKE
DAMPER
FILTER
COOLING COIL

Figure 8. Single-Zone System.

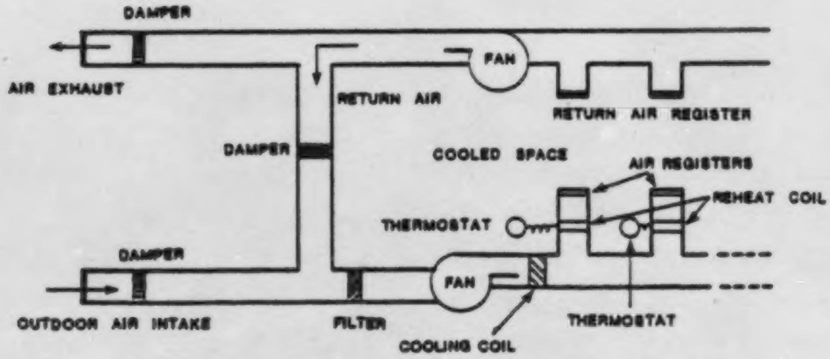

DAMPER
AIR EXHAUST
FAN
RETURN AIR
RETURN AIR REGISTER
DAMPER
COOLED SPACE
AIR REGISTERS
REHEAT COIL
THERMOSTAT
DAMPER
FAN
OUTDOOR AIR INTAKE
FILTER
THERMOSTAT
COOLING COIL

Figure 9. Terminal Reheat System.

Figure 10 shows a multi-zone system in which heated and cooled air are mixed in each zone to reach the desired temperature. These systems can waste energy.

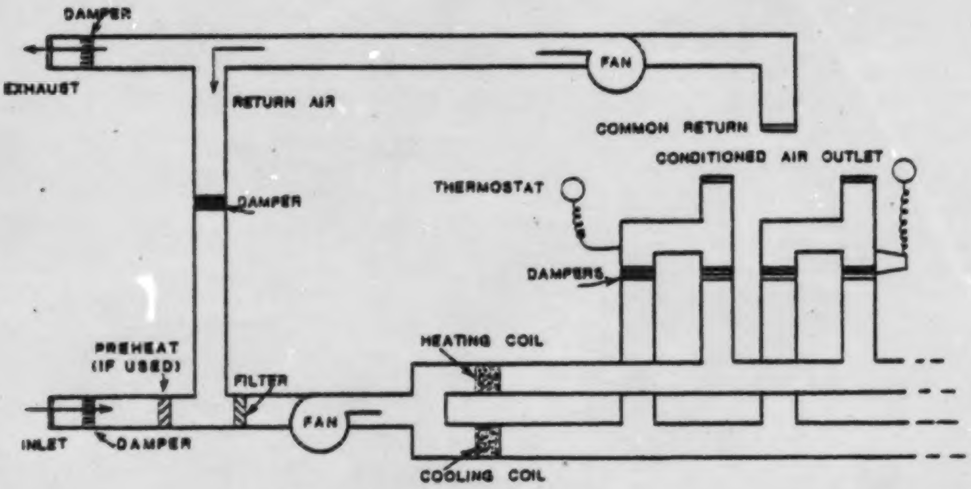

DAMPER
EXHAUST
RETURN AIR
FAN
COMMON RETURN
CONDITIONED AIR OUTLET
THERMOSTAT
DAMPER
DAMPERS
HEATING COIL
PREHEAT
(IF USED)
FILTER
INLET
DAMPER
FAN
COOLING COIL

Figure 10. Multi-Zone System.

Figure 11 shows a dual-duct system that is similar to a multi-zone system. The exception is that both the heated and cooled air are ducted to the space, and the amount of each type of air is controlled with dampers. This system can also waste energy.

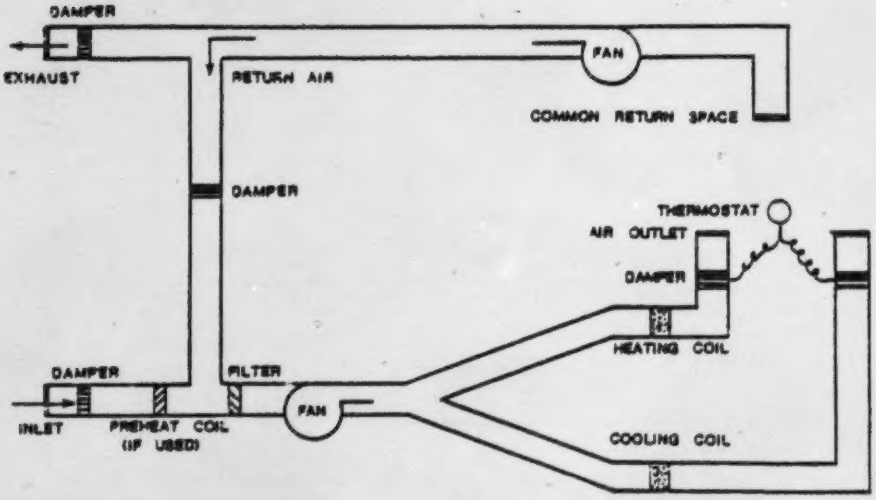

DAMPER
EXHAUST
RETURN AIR
FAN
COMMON RETURN SPACE
DAMPER
THERMOSTAT
AIR OUTLET
DAMPER
HEATING COIL
DAMPER
FILTER
INLET
PREHEAT COIL
(IF USED)
FAN
COOLING COIL

Figure 11. Dual-Duct System.

Figure 12 shows a variable-air-volume system. In this type of system, only cool air is delivered at times when cooling is needed. Temperature is controlled by varying the air flow. Variable-air-volume systems can correct some of the energy wasting features associated with the systems shown in Figures 9-11. However, this discussion will appear later in the module.

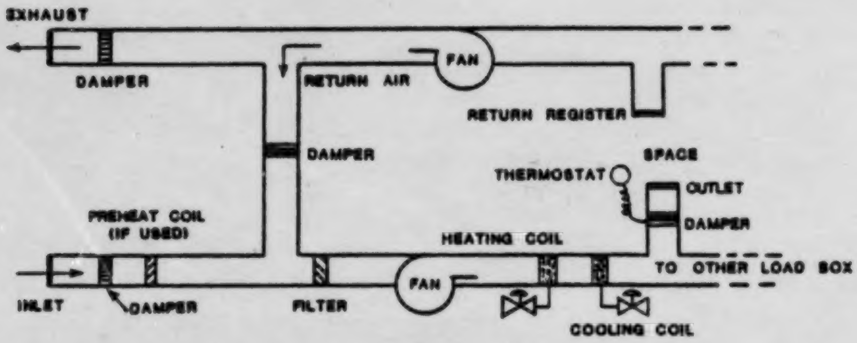

EXHAUST
DAMPER
RETURN AIR
FAN
RETURN REGISTER
DAMPER
SPACE
THERMOSTAT
OUTLET
DAMPER
PREHEAT COIL
(IF USED)
HEATING COIL
TO OTHER LOAD BOX
INLET
DAMPER
FILTER
FAN
COOLING COIL

Figure 12. Variable-Air-Volume System.

Another broad class of cooling systems that has not yet been mentioned is evaporative cooling. The evaporation of water takes up heat, and thus provides cooling. Evaporative cooling is much less expensive than other types of air cooling. However, it is only applicable to certain types of climate — for example, the hot, dry climate of the southwestern United States. Evaporative cooling is not useful in areas where summer humidity is high, like most of the coastal areas of the United States. In much of the northern parts of the United States — from Pennsylvania through the Great Lakes region to Minnesota — it is possible to use evaporative cooling; but its utility is marginal.

ENERGY SURVEY FOR COOLING

An audit of energy use relative to cooling is an important first step for energy conservation in the cooling system of a specific building. This survey is similar to the heating use survey conducted in Module EC-02. A suggested form for an energy survey relative to air conditioning equipment and schedules is shown in Figure 13. This form also contains a checklist of practices relevant to the cooling season. The checklist highlights some of the possible ways to save energy in a specific cooling system. Later — in the Laboratory — the student will prepare an energy survey for a cooling system in a building.

SIZE, GROSS SQ. FT. ______________________

AREA COOLED ____________________________

TYPE(S) OF OCCUPANCY: (% OR SQ. FT.)

Office ______________________________

Warehouse ___________________________

Manufacturing _______________________

Retail ______________________________

Lobbies & Mall (Enclosed) ____________

(Other) ______________________

(Other) ______________________

(Other) ______________________

BUILDING USE AND OCCUPANCY

Fully Occupied: (50% or more of normal)

Weekdays (Hours) ______________ to ______________

Weekends (Hours) ______________ to ______________

______________ to ______________ Sunday

______________ to ______________ Holidays

Remarks: Describe below if occupancy differs for different floors, areas, buildings:

____

____

COOLING SEASON CHECKLIST

Yes No

☐ ☐ 1. Are thermostats set and locked at 78°F or above?

☐ ☐ 2. If thermostats can't be locked, what provisions have been made to keep them at 78°F?

☐ ☐ 3. During nights, weekends, holidays or when the building is unoccupied, is the mechanical cooling shut off?

☐ ☐ 4. Have provisions been made to prevent full use of cooling at night, when only overtime workers are present?

☐ ☐ 5. Have you raised the "cold deck" temperature (leaving temperature from cooling coil) in terminal reheat systems? (58°F is a suggested trial setting.)

☐ ☐ 6. Have you raised the chilled water temperature leaving your chillers at least 2°F?

☐ ☐ 7. On all comfort cooling DX (Direct Expansion) compressors and rooftop units, have you readjusted SUCTION pressures to raise suction temperatures by 4°F?

☐ ☐ 8. Have you reduced outside air brought in by rooftops and all other cooling systems to: 0 CFM unoccupied?

5 to 10 CFM (per person) occupied?

☐ ☐ 9. Have you adjusted economizer control to use outdoor air for cooling?

☐ ☐ 10. Have you reduced light levels to reduce the cooling load?

☐ ☐ 11. Have you adjusted cooling tower water to the lowest practical limit, in order to reduce compressor power needed? (Check with compressor manufacturer for trial values.)

☐ ☐ 12. Have you reduced static pressure on high-pressure fan systems to be consistent with air delivery at farthest unit or space?

Figure 13. Energy Survey Form.

METHODS OF CONSERVING ENERGY

Specific ways in which energy can be conserved in space cooling are presented in the following section of the module. These methods include ...

- control of the chiller operation,
- reduction of building heat load,
- use of outdoor air for cooling,
- control of the cooling coils,
- control of the fans, and
- individual room control.

CONTROL OF THE CHILLER OPERATION

The central chiller is the heart of the cooling system. Various parts of the chiller present opportunities for energy conservation — such as the pumps, compressor, and cooling towers. Automatic control of the chiller can also conserve energy. Specific measures that can be used include ...

- reduction of the compressor head,
- isolation of off-line chillers,
- chiller sequencing and control, and
- spot cooling.

Reduction of the Compressor Head

Reduction of the compressor head will reduce the pumping effort required from the compressor. This reduction can be accomplished by raising the temperature of the chilled water. The valves will then open wider to permit greater flow of the warmer water so as to provide the same cooling. The compressor is then working against a smaller back pressure. The efficiency of a direct expansion chiller increases as the temperature of the chilled water increases. As a rough estimate, the efficiency of the chiller increases about 1.5% for every degree Fahrenheit that the water temperature is raised.

To determine the optimum chilled water temperature, follow these steps:

1. Raise the chilled water temperature one degree at a time and wait for the system to settle out.
2. Observe the positions of the valves supplying chilled water to each cooling zone.
3. Continue raising the chilled water temperature one degree at a time until one valve, supplying the heaviest load, is wide open.
4. If a second valve opens wide, reduce the chilled water temperature.

These steps may be performed automatically under the control of the building automation system. Sensors on each valve determine whether the valve is fully or partially open. When all valves are only partly open, the building control system automatically raises the temperature of the water until one valve is fully open. In this way, changing conditions of cooling load may be compensated automatically.

Isolation of Off-Line Chillers

Sometimes when there is only a small demand for cooling, the cooled water will pass through all the chillers — even when only one chiller is operating. In this case, the water flow is higher than needed – which wastes pump energy. In addition, the water cooled by the operating chiller is mixed with water in the non-operating chillers, thus creating a situation where the operating chiller must cool the water more than is needed. This also wastes energy.

When the cooling demand is low, the inoperative chillers should be isolated so that no water flows through them. The water flow rate should also be reduced. In doing so, it may be necessary to add extra valves to the system; but the energy savings can soon pay for the cost of the valves.

Chiller Sequencing and Control

Many plants have more than one chiller – perhaps a mixture of different sizes and types, all operating together to provide cooling for a building. There is some optimum combination of chillers that can be used for each value of cooling load.

Generally, chillers operate at low efficiency at low values of load (perhaps below 25%), and at very high values of load (perhaps above 90%). Often, the chillers operate at maximum efficiency when the load is between 50% and 90% of capacity. The manufacturer of the chiller will supply data on the efficiency of the chiller versus the load. With this information, one can calculate the proper combination of chillers to use. For a particular set of chillers, the user should calculate the best combination of chillers to use for each load. Then, automatic controls should be installed and programmed to turn the chillers on and off. The correct combination of chillers will provide the best efficiency for changing conditions of cooling demand.

As an example, suppose a plant has three chillers rated at 100, 200, and 400 tons maximum cooling capacity. These chillers all operate with best efficiency at a load of 85% capacity. What combination of chillers should be on when the cooling demand is 500 tons?

If the chillers with capacity 100, 200, and 400 tons are called A, B, and C, respectively, the load of 500 tons can be satisfied by the combinations AC, BC, and ABC. The combination AC would be at 100% capacity, the combination BC at 83.3% capacity, and the combination ABC at 71.4% capacity. The combination BC is closest to the optimum value. Thus, chillers B and C should be turned on by the automatic controller at this value of the cooling load.

Spot Cooling

With large central chillers, there may be some instances when small zones need cooling when most of the building is unoccupied. Some industrial processes, for example, are temperature sensitive and must be cooled at all times – even outside of working hours. This could necessitate running a very large chiller to supply only a small amount of cooling. However, it might be more economical to add a small chiller (or perhaps even a room air conditioner) to supply the small amount of cooling needed for the sensitive zone. Then the large central chiller could be turned off during the hours when the building is unoccupied.

REDUCTION OF BUILDING HEAT LOAD

The requirements for cooling may be lessened by reducing the amount of heat entering the building. Every Btu of heat that is kept out is a Btu of cooling energy that does not have to be supplied.

Some of the possible methods for reducing the heat entering the building involve major structural modifications. Such things could include a change in the orientation of the building to reduce solar exposure and the addition of insulation to reduce heat flow through the walls. Such major changes to the building will be described in Module EC-07 on building construction.

This section will discuss more minor and inexpensive changes that can be implemented. These include ...

- reduction of solar heat gain through windows,
- reduction of heat gain through the roof, and
- reduction of internal heat load.

Addition of insulation in the walls to reduce conduction of heat is less effective in reducing the cooling load in the summer than it is for reducing the heating load in the winter. This is because the difference between indoor and outdoor temperature is usually less in summer than it is in winter. Still, insulation added to reduce heat loss in the winter will have some additional benefit in reducing heat gain in the summer.

Reduction of Solar Heat Gain Through Windows

In summer, the major heat gain through windows is due to solar radiation. Conduction through windows is less. Thus, changing from single glazing to double glazing probably would not be economical just for reducing heat gain in the summer. However, it would be worthwhile for reducing heat loss in the winter, and it would add some small benefit in the summer.

Still, the largest heat gain through windows is from sunlight. The amount depends strongly on the exposure of the window, as well as the amount of incident solar energy at the particular location. Hundreds of additional Btu per year can enter the building for every square foot of window area on south-facing windows.

This added heat gain can be reduced considerably with shading devices. Shading devices include the following:

- External awnings and screens
- Internal drapes, shades, or blinds
- Reflective or tinted glass

The costs of these devices vary considerably, and the reduction of heating load must be balanced against the cost of the device. In many cases, the shading devices can rapidly pay for themselves.

Reduction of Heat Gain Through the Roof

Heat gain through the roof can be reduced by adding insulation to the roof. Another inexpensive method is changing the absorption of the roof. If the color of the roof is changed from dark to light, it will reflect more of the incident solar energy. This can be done with paints or sprays, or on flat roofs, with a thin layer of white pebbles.

The changed roof surface must comply with local restrictions for roofing materials. It must also be durable enough to withstand abrasion. The change in color of a roof to reduce heat load is most effective for buildings that have a large ratio of roof area to floor area — for example, single story buildings.

Reduction of Internal Heat Load

Activities inside the building generate heat that adds to the cooling load. In many cases, the lighting in the building supplies the main contribution to the internal heat load. Other contributions may come from industrial process equipment, furnaces and ovens, motors, office machines, and cooling equipment.

To reduce internal heat loads, the lighting levels should be reduced. This would also save on the electrical energy used to operate the lights. The recommended levels of illumination will be described in Module EC-05 on illumination.

In many cases, the heat from ovens, furnaces, motors, and cooling equipment can be exhausted directly to the outside.

The hot surfaces of pipes, ducts, tanks, and so forth — that are located in air conditioned space — should be insulated.

All of the above measures can reduce the need for cooling to offset internal heat production in the summer.

USE OF OUTDOOR AIR FOR COOLING

Use of outdoor air to cool a building can result in lower cooling costs when the outdoor air has a lower total heat content (enthalpy) than the return air. This can be accomplished by adding an economizer cycle to the system control. The economizer cycle provides for increased intake of outdoor air when conditions are favorable.

Obviously, when the air is relatively cool outside, then it is less expensive to use outdoor air for cooling rather than turning on the air conditioner. However, the controlling factor should be the total heat content (or enthalpy) of the air, rather than the temperature alone.

The operation of an economizer cycle is thus: If cooling is needed in the building and outdoor conditions are favorable, the inlet dampers are opened to increase the intake of air from outside. When the dampers are fully open and further cooling is needed, then the cooling coil is turned on.

In a simple system, the economizer operation is controlled by outdoor air temperature alone. When the outdoor temperature is below some value (typically 72°F, but lower in humid climates and higher in dry climates), the damper opens to admit outdoor air for cooling. For temperatures above the set value (typically 72°F), cooling with outdoor air is not economical. In this case, the outdoor air damper closes to a position that satisfies ventilation requirements only.

This method is not the preferred type of operation. Under some conditions of high relative humidity, the heat content of the outdoor air would be high. There would be a net loss by using outdoor air, even if the temperature were relatively low.

If the economizer cycle uses control of the enthalpy (or heat content) rather than control of temperature alone, the control will be more accurate, and savings will be greater. The load on the cooling coil depends on the total heat in the air, not just the temperature.

A sophisticated economizer cycle will use devices to measure both dry-bulb temperature and relative humidity. The results of these measurements will be input to the controller, which will calculate the enthalpy (heat content) for both the outdoor air and for the return air from the building. The controller will determine which air source will impose the lowest load on the cooling system. If the outside air is the smallest load, then the controller will activate the economizer cycle.

A schematic diagram is shown in Figure 14. This figure shows a simplified psychrometric chart, giving the dry-bulb temperature and enthalpy of the outside air. In the area shown as the hatched part of the diagram, it would be economical to use outdoor air. To the left of this area, the temperature is low, and there would be a mechanical shutoff of the cooling. To the right of the hatched area, either the temperature or the relative humidity would be high, and it would not be economical to use outdoor air.

The savings associated with use of outdoor air depends on the climate. In hot, humid climates, like Florida, the conditions in the summer rarely are ideal for use of outdoor air. In dry climates, like the southwestern United States, conditions are very often ideal.

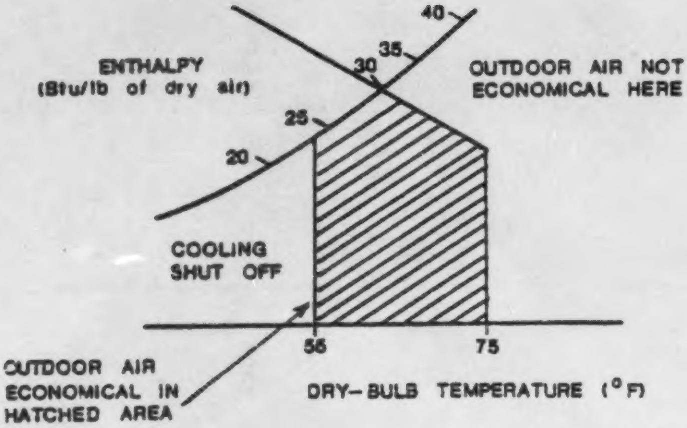

40
35
30
25
20
ENTHALPY
(Btu/lb of dry air)
OUTDOOR AIR NOT
ECONOMICAL HERE
COOLING
SHUT OFF
55
75
OUTDOOR AIR
ECONOMICAL IN
HATCHED AREA
DRY-BULB TEMPERATURE (°F)

Figure 14. Control of Outdoor Air, Based on Enthalpy.

The savings that can be realized from the use of an econimizer cycle can be calculated from the following equation:

$$S = C\left(1 - \frac{V}{100}\right)\frac{K\,H}{50}\,D \qquad \text{Equation 6}$$

where:

S = Savings, in \$/yr.
C = Capacity of the air handling system in the building, in cfm.
V = Minimum ventilation requirement, in %.
H = Number of hours per week that the cooling system is operated.

D = Cost of energy, in $\$/10^6$ Btu.

K = A factor that depends on the climate.

The factor K is usually in the range from 10-20, being relatively low in humid climates and higher in dry climates. For example, K = 10.700 in Houston, Texas, where the humidity is usually high; but K = 20.457 in Las Vegas, Nevada, where the humidity is usually low.

EXAMPLE E: COST SAVINGS, USING ECONOMIZER CYCLE.

Given: An 80,000 square foot office building in Minneapolis, Minnesota, where K = 12.968, the cooling system has a capacity of 60,000 cfm, and for ventilation the dampers have a minimum opening of 3.33%. The cost of cooling energy is \$3 per 10^6 Btu.

Find: The savings associated with an economizer cycle that operates 55 hours per week.

Solution: The savings are given by:

$$60{,}000 \times (1 - \frac{3.33}{100}) \times \frac{12.968 \times 55}{50} \times 3$$

$$= 2{,}482 \text{ \$/yr.}$$

CONTROL OF THE COOLING COILS

The cooling coils which cool the air that circulates through the ducts must be used effectively. In dual-duct systems, air may be cooled in one part of the system and heated in another part. But the method of mixing cooled air and heated air to obtain a desired temperature can result in a waste of energy. The control of the heating coils to avoid this waste has already been described in Module EC-02. The following section of this module describes similar methods for the control of cooling coils to avoid a waste of energy. The appropriate measures include ...

- reset of cold deck temperature (or enthalpy), and
- zone optimization.

Reset of Cold Deck Temperature (or Enthalpy)

The cold deck refers to the part of the duct that contains chilled water coils. If the cold deck is held at a constant temperature, the result will be a waste of energy. The air cooled in the cold deck will be reheated or mixed with warm air at all times except during the maximum cooling demand. If the cold deck controls respond to the area with the greatest cooling demand, energy can be saved. As the demand for cooling is reduced, the cold deck temperature can be raised – a procedure that can be applied to systems in which there are dual hot and cold ducts, as well as to multizone systems.

When cooling demand is low, such systems may waste energy in the following manner: Sometimes air in the cold deck is cooled more than is necessary. Then this air that is too cold must be remixed with warmer air in order to obtain the desired temperature. The energy that it took to warm this air was wasted energy. An increase (or reset) would eliminate much of this energy waste.

Reset of the cold deck temperature should be based on response to the cooling load in the following manner:

Temperature and humidity detectors sense the maximum cooling load. Then, the controller compares the needs of each cooling zone and produces a cooling output that satisfies just the needs of the zone with the greatest demand. This method often allows the cold deck temperature to be reset upwards so that energy is saved. Thus, the reset may be a reset based on enthalpy rather than temperature.

Zone Optimization

Zone optimization is useful for systems that cool the air and then use terminal reheat to produce the desired temperature in each zone. If every zone is reheating, the cold deck is too cold. Cooling energy is being wasted in the cold deck, and, at the same time, heating energy is being wasted at the reheat coils.

Money and energy can be saved by the use of load analyzing controls. The controls measure the demand of each zone and adjust the supply of cold air for the zone so that the reheat energy is minimized. This procedure satisfies the zone with the greatest need for cooling and reduces the supply of cold air to zones that need less cooling. Thus, less energy used for cooling and energy used in terminal reheat may be wasted.

Savings from Improved Cooling Coil Operation

The savings from reset of the cold deck temperature may be determined from the following equation:

$$E = 0.045 \times C \times P_C \times \Delta H \times H_O \times W \qquad \text{Equation 7}$$

where:

E = Energy saved, in Btu/yr.

C = Capacity of the cooling system, in cfm.

P_C = Percentage of air passing through the cold deck.

ΔH = Reset of the cold deck in terms of enthalpy, in Btu/lb.

H_O = Number of hours per week of operation.

W = Number of weeks per year in the cooling season.

For an office building in Chicago with a 20.9 week cooling season, with a 60,000 cfm air handling capacity with 50% of the air flow in the cold deck, and with 60 occupied hours per week, a reset of the cold deck by 1.5 Btu/lb would give an energy saving of ...

$$\begin{aligned} E &= 0.045 \times 60{,}000 \times 50 \times 1.5 \times 60 \times 20.9 \\ &= 253.9 \times 10^6. \end{aligned}$$

At an energy cost of $\$4/10^6$ Btu, this would result in savings of $1016 per year.

CONTROL OF THE FANS

Large fans circulate cooled air through buildings. If the fans are constantly operating, they waste significant amounts of energy. Fans should be controlled so they can be shut off when not needed. The following section discusses two methods for controlling the operation of the fans:

- duty-cycling of fans, and
- equipment scheduling.

Duty-Cycling of Fans

The duty-cycle program conserves energy by shutting down the fans for a portion of their normal operational period. The procedure may be a simple, fixed OFF-period per cycle, or it may be a modulated OFF-period based on temperature. The duty-cycling of the fans is controlled by the building automation system.

Areas that need substantial ventilation are not good candidates for duty-cycling of fans.

Equipment Scheduling

Automatic scheduling of the cooling system save energy in two ways:

- electric energy for operation of fans, and
- cooling energy for ventilation of air.

Energy savings come from a weekly schedule in which equipment is turned on and off in accordance with the hours the building is occupied. The equipment scheduling, under the control of the building automation system, should include varying start and stop times so that morning cool-down time is no longer than needed. The indoor and outdoor temperatures are measured to determine the proper start time.

Flexible scheduling of this type is needed in order to achieve the greatest reduction in the use of cooling energy.

Savings from Fan Control

If fan operation is reduced, the electrical energy savings, in kWh/yr, are given by the following equation:

$$E = 0.8 \times H_p \times H \times W \qquad \text{Equation 8}$$

where:

H_p = Horsepower rating of the fans.

H = Number of hours per week that fan operation is reduced.

W = Number of weeks.

For a reduction of just seven hours per week in fan operation – for a 50-hp fan system, for 52 weeks – the savings would be ...

$$\begin{aligned} E &= 0.8 \times 50 \times 7 \times 52 \\ &= 14{,}560 \text{ KWh.} \end{aligned}$$

At an electrical energy cost of \$0.4/kWh, this is a yearly savings of \$582/yr. Note that this reduction in fan operation can be applied all year, in both the cooling and heating seasons.

INDIVIDUAL ROOM CONTROL

The final part of the system for which savings are possible involves control of the space being cooled. Methods for saving cooling energy in the individual cooling zones include ...

- raising the cooling thermostat setpoint,
- separating heating and cooling setpoints, and
- conversion from constant-air-volume to variable-air-volume.

Raising the Cooling Thermostat Setpoint

The thermostat should be turned up to 78°F (or higher) during the cooling season. Savings of cooling energy result from keeping the temperature at a temperature compatible with new standards. The U.S. Government standard for public buildings is now 78°F during the cooling season, except for buildings for which an exception is granted. (A hospital might be an example of a building for which an exception would be appropriate.)

The cooling thermostat should be locked so that the occupants of the room cannot readjust it.

Separating Heating and Cooling Setpoints

A zero energy band of temperatures should separate the cooling and heating setpoints. When the temperature is in this band, neither heating nor cooling energy is needed.

If the heating thermostat is set at 65°F and the cooling thermostat at 78°F, the zero energy band will range from 65 to 78°F.

Without such a separation, the two thermostats could be turning on the heat and cooling alternately: the cooling system would cool the space, and the heating system would heat it up again. Obviously, this situation is wasteful of energy.

Conversion from Constant-Air-Volume to Variable-Air-Volume

Some buildings mix heated air and cooled air to produce the desired space temperature. If cooling is desired, the amount of cool air in the mixture is increased. The total amount of air delivered to the room is constant. The mixing controls the temperature.

This procedure is wasteful since energy was used to heat the warm air and to cool the cool air. A better method would be to control the volume of air entering the room. If cooling is desired, the volume of cool air is increased; then, when the temperature reaches the desired value, the flow of cool air is reduced. Heated air is not used since it is not needed.

The conversion from constant-air-volume to variable-air-volume is easily accomplished in many cases simply by using an automated control for the dampers that control the air flow. Often, the need for replacement of equipment is minimal.

Savings from Individual Room Control

The savings in energy from proper control of the temperature in cooled areas may be determined from the following equation:

$$E = F \times \Delta T \times H \times W \qquad \text{Equation 9}$$

where:

E = Energy savings, in Btu/yr.
F = A factor defining heat transfer from the building.
ΔT = The amount by which the temperature is increased in the cooled area, in °F.
H = Number of hours per week that the temperature is increased.
W = Length of the cooling system, in weeks.

The factor F is in units of Btu/hr/°F. This factor varies from building to building, depending on the size, type of construction, insulation, number of windows, and so on.

As an example, an 80,000 square foot, two-story office building has a heat transfer factor F equal to 16,200 Btu/hr/°F. If the cooling thermostat setpoint is increased from 74°F to 78°F for 24 hours a day, for seven days a week, for a cooling season 20.9 weeks in length, the annual savings will be ...

$$E = 16{,}200 \times 4 \times 168 \times 20.9$$
$$= 227.5 \times 10^6 \text{ Btu.}$$

At a cost of $\$4/10^6$ Btu, this will be a savings of \$910/yr.

EXERCISES

1. List, describe, and explain conservation measures related to the following:
    a. Control of chiller operation
    b. Reduction of building heat load
    c. Use of outdoor air for cooling
    d. Control of the cooling coils
    e. Control of the fans
    f. Individual room control
2. Define the following terms:
    a. Wet-bulb temperature
    b. Dry-bulb temperature
    c. Hygrometer
    d. Psychrometric chart
    e. Relative humidity
    f. Coefficient of performance
3. Consider the following: A school in New Orleans, Louisiana, has a climate factor K that is equal to 11.137, with air capacity at 50,000 cfm and minimum ventilation of 5%. If energy for cooling costs $\$4/10^6$ Btu, what would be the annual savings if an economizer cycle is used for an operating period of 40 hr/wk?
4. In a factory in Oklahoma City that has a 29.5-week cooling season, the cooling system has a capacity of 120,000 cfm. If the cold deck is reset by 1.7 Btu/lb for an operating time of 55 hr/wk, what are the annual savings? Assume cooling energy costs $\$3.67/10^6$ Btu and that 50% of the air flows through the cold deck.
5. For an office building in New York City that has a 20-week cooling season, the operation of the fans is reduced by 8 hr/wk. For a 100-hp fan system, what are the annual savings if electricity costs 4.5¢/kWh?

6. For an apartment building in Memphis, Tennessee, where the cooling season lasts 30.4 weeks, the thermostat setpoint is increased from 72°F to 78°F, 24 hours each day. If the building has a heat transfer coefficient of 30,000 Btu/hr/°F, what are the annual energy savings, expressed in Btu?

LABORATORY MATERIALS

Hygrometer
Anemometer

LABORATORY PROCEDURES

In these experimental procedures, the student will prepare an energy survey for cooling in a particular building. The student will also measure the refrigeration effect produced by the cooling system in the building, as well as the coefficient of performance for the cooling system.

A sling hygrometer may be used, but other types of hygrometers are also acceptable. A hot wire anemometer may be used. Other types of anemometers are also acceptable.

The student must have access to the cooling system in some building. A building (a school or office, for example) with a large central chiller is preferable. Officials at the school where this course is offered may be cooperative in providing access to the cooling system. If no other building is available, a private home with a central air conditioning system could be used; however, this is not preferred.

1. Carry out an energy survey of the cooling system. Use the form and checklist provided in the Data Table. Do not be concerned if it is difficult to find all the information. Building maintenance personnel may be helpful in locating some of the items.
2. Measure the total cooling effect from the cooling system. Access to the duct system upstream and downstream of the cooling coil will be needed.
   a. Use the hygrometer to measure wet-bulb temperature and dry-bulb temperature. Measure both quantities both upstream and downstream of the cooling coil. Then use Figure 7 to determine the enthalpy both upstream and downstream of the cooling coil.
   b. Then determine the capacity of the cooling system. Measure the velocity V (ft/min) of the air in the duct, using the anemometer. Measure the cross-sectional area of the duct (in ft^2). The capacity C in cfm is then given by the following ...

$$C = V \times A$$

   Enough information has been found now to use Equation 4 in calculating the cooling effect (Btu/hr) produced by the cooling system.
   c. If the cooling system has suitable flowmeters and temperature measuring devices on the cooling water, use them to measure water flow and temperature of the water as it flows into and out of the chiller. Then use Equation 5 to calculate the cooling effect. Compare the result to that obtained from the air temperature measurements.

3. Measure the coefficient of performance of the cooling system. Use the rated voltage and amperage of the chiller in Equation 3 to obtain the input. The power factor is difficult to determine. The building engineer may be able to supply an estimate. Otherwise, use an estimated value of 0.9. Calculate the input; then use the result, along with the earlier determination of cooling effect in Equation 1, to determine the coefficient of performance of the cooling system. Remember to use consistent units for the two quantities.

DATA TABLE 1. ENERGY SURVEY FORM.

SIZE, GROSS SQ. FT. ____________________

AREA COOLED ____________________

TYPE(S) OF OCCUPANCY: (% OR SQ. FT.)

Office ____________________

Warehouse ____________________

Manufacturing ____________________

Retail ____________________

Lobbies & Mall ____________________
(Enclosed)

(Other) ____________________

(Other) ____________________

(Other) ____________________

BUILDING USE AND OCCUPANCY

Fully Occupied: (50% or more of normal)

Weekdays (Hours) ____________ to ____________

Weekends (Hours) ____________ to ____________

____________ to ____________ Sunday

____________ to ____________ Holidays

Remarks: Describe below if occupancy differs for different floors, areas, buildings:

____

____

COOLING SEASON CHECKLIST

Yes No

☐ ☐ 1. Are thermostats set and locked at 78°F or above?

☐ ☐ 2. If thermostats can't be locked, what provisions have been made to keep them at 78°F?

☐ ☐ 3. During nights, weekends, holidays or when the building is unoccupied, is the mechanical cooling shut off?

☐ ☐ 4. Have provisions been made to prevent full use of cooling at night, when only overtime workers are present?

☐ ☐ 5. Have you raised the "cold deck" temperature (leaving temperature from cooling coil) in terminal reheat systems? (58°F is a suggested trial setting.)

☐ ☐ 6. Have you raised the chilled water temperature leaving your chillers at least 2°F?

☐ ☐ 7. On all comfort cooling DX (Direct Expansion) compressors and rooftop units, have you readjusted SUCTION pressures to raise suction temperatures by 4°F?

☐ ☐ 8. Have you reduced outside air brought in by rooftops and all other cooling systems to: 0 CFM unoccupied?

5 to 10 CFM (per person) occupied?

☐ ☐ 9. Have you adjusted economizer control to use outdoor air for cooling?

☐ ☐ 10. Have you reduced light levels to reduce the cooling load?

☐ ☐ 11. Have you adjusted cooling tower water to the lowest practical limit, in order to reduce compressor power needed? (Check with compressor manufacturer for trial values.)

☐ ☐ 12. Have you reduced static pressure on high-pressure fan systems to be consistent with air delivery at farthest unit or space?

REFERENCES

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. ASHRAE Handbook, 1975 Equipment. Chapters 6 and 18. New York (1975).

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. ASHRAE Handbook, 1977 Fundamentals. Chapter 5. New York (1977).

Baron, S.L. "Facility Modifications," Manual of Energy Saving in Existing Buildings and Plants. Vol. II. Chapter 3. Englewood Cliffs, NJ: Prentice Hall, Inc., 1978.

Honeywell, Inc. Energy Conservation with Comfort. Minneapolis, MN: Honeywell, Inc., 1979.

Jennings, B.H. Environmental Engineering. Chapter 6. Scranton, PA: International Textbook Co., 1970.

O'Keffe, John and Whitteker, J.K. "Air Conditioning and Ventilation," Standard Handbook for Mechanical Engineers. T. Baumeister, ed. New York: McGraw-Hill Book Co., 1967.

TEST

Fill in the blanks.

1. Conservation methods related to control of chiller operation include reduction of the __________ load, ___________ of off-line chillers, chiller _________ and control, and _________ cooling.
2. Conservation methods for cooling related to reduction of building heat load include reducing _____________ ______________ through windows, reducing ___________ ________ through the roof, and reducing the _________ heat load.
3. Use of outdoor air for cooling is accomplished with an ____________ cycle.
4. Control of the cooling cycle can include ___________ of cold deck temperature and ________________ optimization.
5. Conservation measures related to control of fans include ___________________ of the fans and equipment _______________.
6. Conservation measures related to individual room control include raising the cooling thermostat _________ ______________, ______________ heating and cooling setpoints, and conversion from constant air volume to ___________________________.
7. The cooling thermostat should be set no lower than __________.
8. The _______________ measures wet-and dry-bulb temperatures.
9. The components used in a refrigeration cycle include a compressor, a _______________, an _________________, and an _____________.

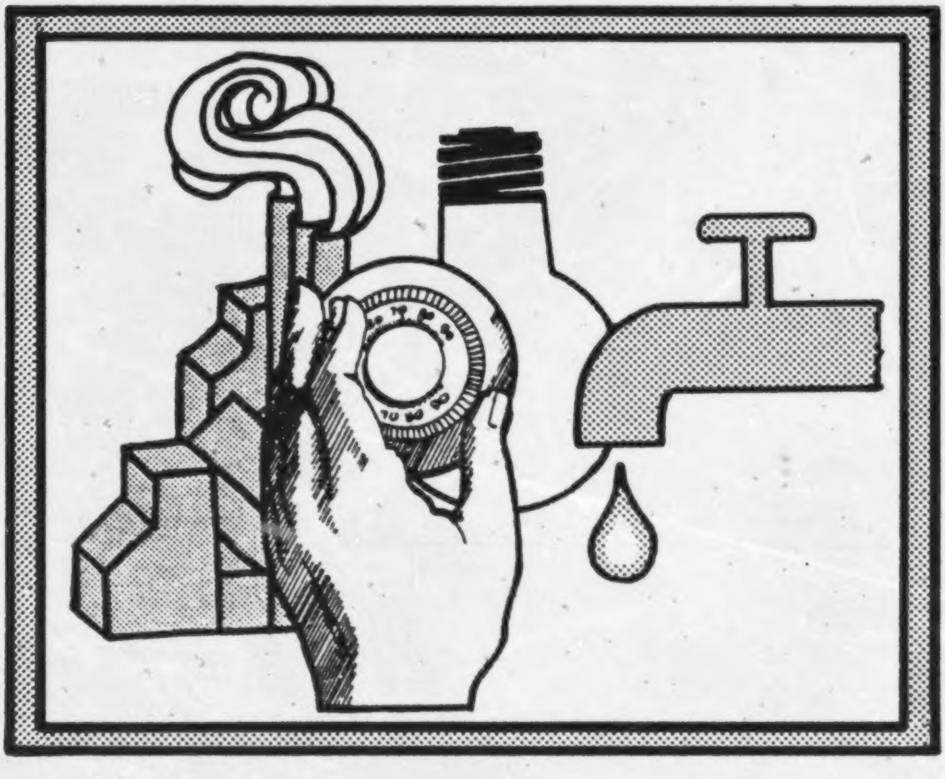
10. The total heat content of moist air is called ______ ________.

ecut

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-04

CONSERVATION PRINCIPLES AND EFFICIENCY MEASUREMENTS - HOT WATER AND STEAM SUPPLY SYSTEMS

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module is designed to give the student specific skills to improve the energy efficiency of hot water and steam systems. It also defines and identifies the variables associated with energy loss and discusses specific methods for reducing energy loss.

PREREQUISITES

The student should have a basic understanding of algebra and physics and should have completed Modules EC-01 through EC-03 of Energy Conservation.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Perform calculations related to the transfer of heat energy.
2. Define the following terms:
    a. Conduction.
    b. Convection.
    c. Radiation.
3. List causes of pressure and flow loss.
4. Describe methods of reducing energy consumption in hot water and steam supply systems. Include methods that reduce the load, reduce losses, and increase efficiency.
5. Conduct an energy survey for a steam or hot water supply system in a specific building.

6. Estimate the amount of energy that can be saved by adding insulation to steam or hot water pipes.
7. Make measurements on the temperature of a hot water or steam distribution system in a particular building.

HOT WATER AND STEAM SUPPLY SYSTEMS

In many systems, heat is transferred from a furnace or boiler to a remote point by a hot fluid – either steam or water. For a given volume of the fluid, steam and water are capable of delivering more heat than air. Thus, heat transfer using water or steam requires relatively small pipes, whereas heat transfer using air requires larger ducts.

This module describes methods that can be used to reduce losses of energy in the transfer of heat by hot water or steam.

HOT WATER SYSTEMS

Hot water systems use components that are long-lived and relatively simple. Thus, with reasonable maintenance, hot water systems can operate efficiently over long periods of time. In these systems, water is heated in a boiler or in a heat exchanger and is then delivered to a remote location through pipes. The heat from the water can be used for either space heating or for industrial processing. Circulation of the water through the pipes can be accomplished by either the forced or natural method. In a system using natural circulation, the heated water expands and rises. Colder water then flows in to take its place. Thus, the circulation is driven by differences in density between hot and cold water. In a system using forced circulation, pumps drive the water through the system. Most modern systems now being installed are the forced circulation types, although some natural circulation systems are still in use.

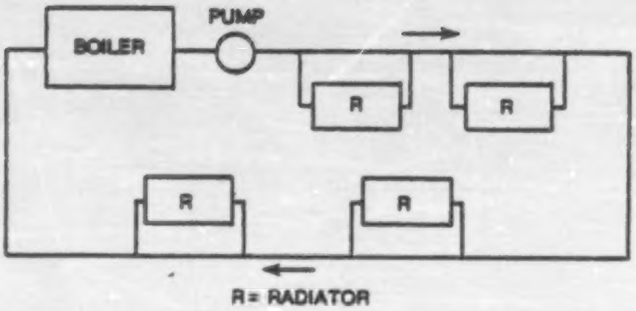


Figure 1. Schematic Diagram of Single-Pipe Hot Water System.

There are numerous arrangements for hot water circulation systems, but the two basic types are the single-pipe system and the two-pipe system. Figure 1 shows the elements of a single-pipe system. In this system, water heated in the boiler is driven by the pump through the main pipe. This single pipe carries the water in a loop and finally returns the cooled water to the radiator. At points where heat is needed (shown in Figure 1 as radiators for space heating), hot water flows through connecting piping to the radiators. The water flows through the radiators and then rejoins the flow in the main pipe.

The design of a two-pipe hot water system is shown in Figure 2. The dashed line shows the return part of the circuit. The cooler water emerging from a radiator joins the return line but does not circulate through additional radiators. In this design, higher water temperatures are maintained at each radiator in the circulation loop.

Components used in hot water systems include pumps, valves, expansion tanks, and pressure relief valves. The pumps are usually the centrifugal type that use a rotating impeller on a horizontal shaft driven by an electric motor. The valves, which may be either manually or electrically actuated, are used to close off parts of the system — for example, to

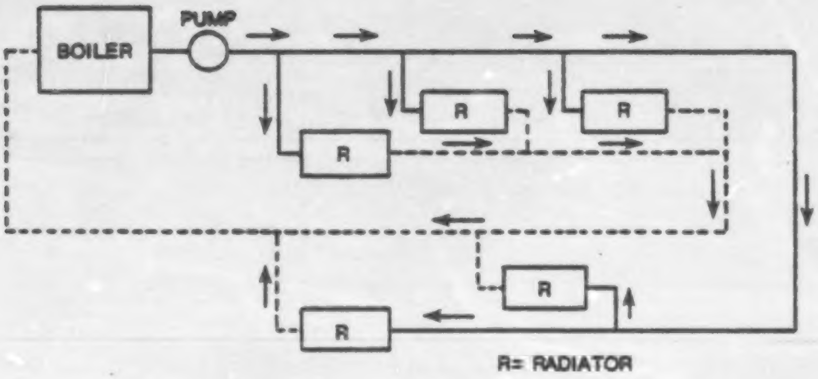


Figure 2. Schematic Diagram of Two-Pipe Hot Water System (Arrows Show Direction of Flow).

shut off a particular radiator. They are also used to add water to the system when necessary. The expansion tank is needed because of the difference in volume between hot and cold water. Air is trapped in the tank and is compressed as the water heats and expands. If the air pressure in the tank increases too much, water is released through the relief valve.

STEAM SYSTEMS

In steam systems, the circulating hot fluid is steam. In many cases, the basic system design is similar to that of hot water systems. In some cases, a hot water system can be converted to steam, or vice versa. The use of superheated steam does allow for higher temperatures than water systems can supply. Because of this, industrial process heat can be supplied at higher temperatures than would be possible with hot water.

Both the one-pipe and the two-pipe design can be used in steam systems. The considerations are similar to those involved in one-pipe and two-pipe hot water systems. The one-pipe steam system uses a single main pipe to carry steam from the boiler and eventually return it to the boiler as a wet consensate. The steam is diverted into radiators or other heat exchangers at each point where heat is needed; then it is returned to the main line.

The two-pipe steam system has two branches in which steam and condensate flow separately. The steam flows into each radiator in the steam branch and then emerges directly from the radiator into the return branch. The general design is similar to that of the two-pipe water system.

The flow of steam in the pipes is driven by pressure differences. When the boiler produces steam, the volume of the steam is much greater than that of the water which was boiled. The resulting pressure increase drives the steam through the pipes. At the other end of the system, the steam condenses back to water, the volume shrinks, and the pressure drops. This procedure increases the pressure difference and helps to drive the flow. Because of the greater pressure differences possible in steam systems, many steam systems only use natural circulation, without pumps.

In some cases, gravity alone does not expedite the return of the condensed steam to the boiler — in which case, pumps are used to drive the water back to the boiler.

Components used in steam systems often include air vents, pressure relief valves, and pumps. Because the pipes usually contain some air when the steam is produced, the air must be vented to allow efficient flow of steam. Air valves are designed to allow air to flow out, but they will close when steam begins to escape. Pressure relief valves are needed for safety. Centrifugal pumps may be used in cases where steam is condensed into water and then pumped back as water into the boiler. In other cases, vacuum pumps are used on the return side of a steam system in order to maintain a desired pressure difference. The vacuum pump produces a reduced pressure (usually below atmospheric pressure) which allows more efficient flow of the steam.

Both steam and hot water heat transfer systems can operate with high efficiency. However, there are many places where energy can be lost from either system. For instance, heat may be transferred directly out of the pipes at the places where it is not needed; or, a malfunction of valves or other components can cause loss of pressure or reduced flow. A well designed monitoring and maintenance program can reduce these energy losses.

TYPES OF HEAT LOSS

Heat can be transferred from hot bodies by three methods: conduction, convection, and radiation. Many of the components in heating or cooling systems have a temperature that is different from their surroundings. The ducts and pipes that carry hot air or hot water can lose heat to the surrounding areas, or the ducts and pipes carrying a coolant can gain heat. In either case, the heat transfer process can result in a loss of energy. Significant transfer of heat energy can occur by each of these three methods; therefore, each is important in the design and operation of heating or cooling equipment.

For a more specific description of heat transfer, emphasis is placed on heat loss from hot bodies; but the student should remember that heat gain by cooled materials will occur in the same way.

CONDUCTION

If one end of a piece of material is at a high temperature and the other is at a low temperature, heat energy will flow from the hot end to the cold end. A spoon with one end in a pan of boiling water will soon burn a hand holding the other end, for example. This transfer of heat energy occurs by a process called conduction. Conduction involves collisions of atoms with their neighbors and a transfer of energy between the atoms. As a net result, heat energy is transferred through the material.

Conduction of heat occurs only when different parts of the material are at different temperatures. The heat energy always flows from a region of high temperature to a region of lower temperature. Thus, conduction may be defined as "the flow of heat through a material because of temperature difference."

The amount of heat flow through a piece of material of x amount of feet thickness is given by the following equation (Equation 1):

$$Q = K\,A\,(T_h - T_c)/x \qquad \text{Equation 1}$$

where:

Q = The amount of heat flow, in Btu/hr.
K = A property of the material, called the thermal conductivity.
A = The cross-sectional area of the material, in square feet (area perpendicular to the direction of heat flow).
T_h = The temperature of the hot side, in °F.
T_c = The temperature of the cold side, in °F.

The thermal conductivity has units Btu/hr/ft/°F — which is sometimes written as Btu/hr/ft^2/(°F per ft). This tends to be high for materials with high electrical conductivity (like metals) and tends to be low for materials with low electrical conductivity (like electrical insulators). Some values of thermal conductivity are presented in Table 1. Note that these values vary over a wide range. Because of this fact, the amount of heat flow can be changed by the choice of material. If an insulating material is used, heat losses by conduction can be significantly reduced. Thermal conduction transfers heat from the hot fluid inside a pipe or duct to the outside, and insulation around the pipe or duct can reduce this heat loss.

TABLE 1. VALUES OF THERMAL CONDUCTIVITY.

Material	Thermal Conductivity (Btu/hr/ft/°F)
Aluminum (alloy)	128.00
Asbestos insulation	0.09
Brick	0.40
Concrete	0.54
Copper	227.00
Glass (silicate)	0.59
Iron (cast)	27.60
Nickel	34.40
Plaster	0.43
Steel	26.20
Wool	0.02

EXAMPLE A: HEAT LOSS BY CONDUCTION.

Given: A window of silicate glass has an area of eight square feet and a thickness of 0.25 inch. Suppose that the inside surface is at the temperature of the indoor air (70°F) and the outside surface is at the temperature of the outside winter air (0°F).

Find: How much heat passes through the window by conduction?

Solution: The thickness is 1/48 foot. The thermal conductivity (from Table 1) is 0.59 Btu/hr/ft/°F. Inserting the values in the equation for heat conduction gives the following:

Example A. Continued.

Q = 0.59 x 8 x (70 - 0)/(1/48)
Q = 15,900 Btu/hr.

CONVECTION

Convection refers to the transfer of heat from one place to another by the movement of hot material. Convection may be forced – for example, by a pump or a blower. The pump or blower causes a hot fluid to move around and, thus, to deliver heat from one place to a different place. An example is a hot-air heating system. Air that was heated in the furnace is moved by the blower through ducts to the spaces where heat is needed.

Heat flow by convection can also occur without blowers, fans, or pumps, forcing the fluid to move. The differences in density (in the fluid) and the action of gravity will cause fluid to move and to transfer heat. For example, air that is near a hot surface will be warmed by conduction of heat. This warmed air will be less dense and will flow upwards. The cooler air that continues to replace the air that was warmed and moved upwards is, in turn, warmed and also moves upwards. Thus, convection can be a source of heat loss for hot pipes, ducts, furnace walls, and so forth. Convection that occurs in this manner is called natural convection, or free convection.

The mathematical relationships that describe the transfer of heat by convection are complicated and depend strongly on the exact situation. For example, natural convection depends on whether the surface is flat or curved, horizontal or vertical, and so on. The equations describing convection can assume a variety of forms. Although it is beyond the scope of this module to give a mathematical description of convection, it is important to note that convective heat loss can be a serious source of energy loss from hot components in a heating system.

RADIATION

Warm bodies radiate heat energy as electromagnetic radiation. Bodies that are very hot (red hot or white hot) glow visibly; they emit radiation as visible light. Bodies that are somewhat less warm do not emit visible light, but they do emit radiation at longer wavelengths in the infrared portion of the spectrum. The emission of radiant energy by a heated body can account for a significant amount of energy loss. The transfer of heat as radiant energy is called radiation.

The amount of radiant energy emitted by a surface is strongly dependent upon temperature. It also is dependent upon the nature of the surface. The amount of radiant energy can be expressed by the following equation (Equation 2):

$$E = \sigma A \varepsilon T^4 \qquad \text{Equation 2}$$

where:

σ = A constant which has a numerical value of 1.713×10^{-9} Btu/hr/ft^2/(R)^4.

A = The surface area of the body.
ε = A dimensionless quantity called the emissivity.
T = The temperature, in degress Rankine (R).

When these units are used, the radiated energy E is in Btu/hr. The temperature must be expressed as an absolute temperature, in degrees Rankine. The expression of temperature in degrees Rankine is related to the Fahrenheit temperature by the following relation (Equation 3):

$$T_R = T_F + 459.7 \qquad \text{Equation 3}$$

where:

T_R and T_F = The temperatures in degrees Rankine and degrees Fahrenheit, respectively.

For purposes of this module, it is accurate enough to approximate the value of the Rankine temperature by using Equation 4 below:

$$T_T = T_F + 460 \qquad \text{Equation 4}$$

(Note that one cannot use the temperature in degrees Fahrenheit – nor in degrees Celsius – in the equation for thermal radiation.)

The emissivity is a property of the surface, and is strongly dependent upon the exact condition of the surface. The emissivity is dimensionless and has a numerical value lying between 0 and 1.

For a particular material, the value will depend on whether the surface is clean or dirty, rough or smooth, oxidized or unoxidized, and so forth. Thus, one cannot specify exact values of emissivity for different materials. Table 2 presents some typical values of emissivity for some common materials; however, these values are only approximations. Since the metals used for pipe and ducts are not polished and may be rough and oxidized, a typical value for the emissivity of a bare metal pipe or duct might be in the range of 0.2 to 0.3.

TABLE 2. TYPICAL VALUES OF EMISSIVITY FOR SOME MATERIALS.

Material	Emissivity
Asbestos	0.93 - 0.95
Lampblack (carbon)	0.99
Metals, dull and oxidized	0.2 - 0.3
Metals, polished	0.05 - 0.10
Organic Materials (Paper, Rubber, Wood, etc.)	0.8 - 0.95
Paint	0.8 - 0.9
Plaster, rough	0.91

The radiant energy emitted by the body travels with the velocity of light. When it strikes another surface, it may be absorbed and warm that surface. Thus, a hand held near a hot body will feel warmth, even in the absence of convection.

For pipes and ducts carrying hot fluids, radiation can produce a loss of heat energy.

EXAMPLE B: EMISSION OF RADIANT ENERGY.

Given: A pipe 10 feet long, with a 6-inch outside diameter has a temperature of 200°F. The pipe is painted black with a paint having an emissivity of 0.9.

Find: How much energy is radiated by the pipe.

Solution: The area of the pipe is $\pi \times \frac{1}{2} \times 10\ \text{ft}^2$.

The absolute temperature is $460 + 200 = 660$ R.

Using the formula for thermal radiation gives:

$$1.713 \times 10^{-9} \times \pi \times \frac{1}{2} \times 10 \times 0.9 \times (660)^4$$

$$= 4600 \text{ Btu/hr radiated by the pipe.}$$

PRESSURE AND FLOW LOSS

The pressure and flow in a circulating fluid distribution system are related according to the particular characteristics of the system. This is shown schematically in Figure 3, which relates the pressure drop in the system and the flow through the system. The curve expressing the relation is called the system characteristic curve.

The shape of the system characteristic curve for a specific system is determined by the length and diameter of the piping, as well as by the size and shape of valves and pipe fittings. These parameters determine the resistance of the system to flow.

Losses in pressure or in flow can cause excess energy consumption in hot water or steam supply systems. If there are pressures losses, there will be extra load on the circulating pumps to provide the needed flow. If there are flow losses, the system pressure must be increased to make up the loss. However, this will also increase the load on the pumps.

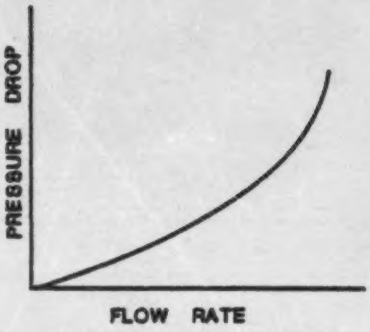


Figure 3. Schematic Diagram of a System Characteristic Curve.

The relation between pressure and flow in the system is as follows:

Pressure = Flow x Resistance to Flow

In this relation, the resistance to flow is a characteristic of the system. This relation is analogous to the following electrical relation:

Voltage = Current x Electrical Resistance

In this analogy, the pressure corresponds to voltage, the flow corresponds to electrical current, and the resistance to flow corresponds to electrical resistance.

There are are a number of possible causes for loss of pressure or flow. Loss of pressure can be caused by the following factors:

- Leaks in components
- Malfunction of pumps or valves

Leaks may be present in components such as pressure relief valves, control valves, pipe fittings and joints, pumps, air venting valves, and so on. Leaks can often be detected by visual inspection. Malfunction of components such as pumps or valves may be more difficult to detect. Measurement of flow and pressure drop assists in the detection of such malfunctions.

Flow loss may arise from the following causes:

- Leaks in components
- Loss of pressure
- Faulty flow control components
- Faulty metering
- Clogged filters

A partial blockage of flow can sometimes be located by the use of pressure measurements. For example, if a filter is partially clogged, there will be a pressure drop across the filter. If the difference in pressure upstream and downstream from the filter increases above its normal value, this condition will indicate partial blockage of the filter. Simple temperature measurements can often identify parts of the system in which flow is below normal. If the flow is reduced in certain parts of the system, the temperature will also be reduced. Thus, a measurement of the surface temperature of the pipes can help to diagnose partial or complete blockages of flow.

ENERGY SURVEY FOR STEAM AND HOT WATER SUPPLY SYSTEMS

An audit of the condition of steam and hot water supply systems can be an important first step relative to energy conservation for these systems. An audit information form and a suggested checklist for an energy survey for steam and hot water supply systems are shown in Tables 3 and 4. The checklist can highlight some of the possible ways to save energy in a specific system. Later the student will prepare an energy survey for a steam or hot water supply system in a particular building.

TABLE 3. AUDIT INFORMATION FOR A STEAM AND HOT WATER SUPPLY SYSTEM.

Building Size (Square Feet) ____________

Types of Occupancy (% or Square Feet)

Office ____________

Warehouse ____________

Manufacturing ____________

Retail ____________

Lobbies or Mall ____________

Other ____________

Building Use and Occupancy

Fully occupied (50% or more of normal)

Weekdays (hours) _____ to _____

Weekends (hours) _____ to _____

_____ to _____ Sundays

_____ to _____ Holidays

Steam and Hot Water Use (Percent)

Space heating ____________

Domestic uses (handwashing, dishwashing, etc. ____________

Industrial process heat ____________

Capacity

Steam system (gallons per minute) ____________

Hot water system (gallons per minute) ____________

TABLE 4. AUDIT CHECKLIST FOR A STEAM AND HOT WATER SUPPLY SYSTEM.

Yes	No		
☐	☐	1.	Are the exterior surfaces of boilers and storage tanks insulated?
☐	☐	2.	Are the pipes for steam and hot water flow insulated?
☐	☐	3.	Are valve bodies, fittings and other pipe appurtenances insulated?
☐	☐	4.	Is the insulation thick enough so that the outer surface does not exceed 90°F when the system is operating at full load?
☐	☐	5.	Have steam traps passing steam along with condensate been repaired or replaced?
☐	☐	6.	Have any leaks in pipes, pipe joints, or pressure relief valves been sealed?
☐	☐	7.	Has the water temperature been reduced for uses which do not need the highest water temperature?
☐	☐	8.	Have spray type water faucets that reduce water usage been installed?
☐	☐	9.	Have pressure reducing valves been installed in steam lines which do not need the highest pressure?
☐	☐	10.	Has a separate small heater for summer use been installed if the space heating system is used for hot water or steam generation?
☐	☐	11.	Are the circulating pumps turned off during periods when no hot water flow is needed?
☐	☐	12.	Are restrictions to flow in the system removed so as to reduce pump load?
☐	☐	13.	Have the pumps and valves been checked for proper functioning?
☐	☐	14.	Has torn or worn insulation been replaced?

METHODS OF REDUCING ENERGY CONSUMPTION IN HOT WATER AND STEAM SUPPLY SYSTEMS

There are various approaches to the reduction of energy consumption in hot water and steam supply systems. The approaches may be considered in three general categories:

- Reducing the consumption of hot water or steam
- Reducing losses in the system
- Increasing the efficiency of the system

REDUCING THE CONSUMPTION OF HOT WATER OR STEAM

The consumption of hot water and steam may be reduced by several methods:

- Reduction of use
- Lowering the temperature
- Supply of hot water or steam at no more than the required temperature for most applications

Use of domestic hot water (used for such things as handwashing and kitchen purposes) can be reduced by installing self-closing faucets on hot water taps and by installing spray orifices to reduce the flow at the tap. In buildings where cooking facilities are not in constant use, the hot water supply to the kitchen could be turned off when the kitchen is not in use. Old kitchen equipment (like dishwashers) may use water exessively. Such equipment should be replaced with newer equipment that uses less water.

When hot water or steam is used for industrial process heat, the amount of usage should be examined carefully. The heating supply need may have been established when energy was more plentiful and may not reflect the real need – which might be considerably lower. If the real need for heat in the process is determined, then only the necessary amount of hot water or steam that will carry out the process can be supplied without wasting energy.

Reducing the usage of hot water and steam amounts to large savings of energy – energy that would be used to heat the water or steam. Futhermore, there are the savings of energy associated with pumping the water or steam through the system. Water pumps, in particular, use a great deal of energy. Reducing the load on the system will reduce energy consumed by the pumps.

The amount of energy consumed by the pumps as they circulate water is given by Equation 5:

$$E = 9.1 \times 10^{-7}\ H \times G \times W \qquad \text{Equation 5}$$

where:

E = The energy used, in 10^6 Btu/yr.
H = The head of the water system, in ft.
G = The flow rate, in gal/min.
W = The number of hours per year that the system is used.

Equation 5 assumes a pump efficiency of 70%.

For a system with a 100-foot head, which is used continuously (8760 hr/yr) and is pumping 500 gal/min, the pumps alone use 4×10^8 Btu/yr, according to the Equation 5. If the flow were reduced to 400 gal/min, the energy usage would be 3.2×10^8 Btu/yr, a savings of 8×10^7 Btu/yr.

Lowering water temperature may also reduce energy consumption. If the water temperature is higher than necessary, it will simply be diluted with cold water at the point of usage. Thus, the heat needed to raise the water to the original higher temperature is wasted. An example is water used for handwashing. If the water is very hot, it will be diluted with cold water. If it were delivered to the faucet at the proper temperature for handwashing, however, it would not require dilution, and that extra amount of energy would be saved.

The amount of energy that can be saved annually by lowering water temperature by an amount dT (in Fahrenheit degrees) is given by Equation 6:

$$E = 8 \times G \times dT \qquad \text{Equation 6}$$

where:

E = The annual energy savings, in Btus.
G = The annual usage of water, in gallons.

If the occupants of a large office building use 100,000 gallons of water per year for handwashing, reducing the water temperature in that building from 125°F to 100°F can save:

$$8 \times 100{,}000 \times 25 = 20{,}000{,}000 \text{ Btu/yr.}$$

Of course, water temperature cannot always be reduced. An example is dishwashing, where a high temperature is needed for sterilization. Other examples include some industrial processes that need high temperatures for successful operation.

However, even in situations where there is a critical need for high water or steam temperature, the possibilities for energy conservation still exist. For instance, when a central generator supplies hot water or steam for a number of uses that require different temperatures, the temperature can be reduced at the central generator to a value that will satisfy most of the requirements. Then, booster heaters can be installed near the specific locations that need higher temperatures.

Thus, the temperature of water or steam can be reduced to the minimum value needed for most applications, while those applications requiring higher temperatures can still receive them. This method is more energy conserving than when hot water or steam is produced at the maximum temperature and then cooled or diluted at locations that use a lower temperature.

REDUCING LOSSES IN THE SYSTEM

Reduction of losses in the system is an effective method of conserving energy. Since many steam and hot water distribution systems were installed at times when energy conservation was not as important a consideration as it today, efforts to reduce losses in these systems are becoming more popular. Such efforts include the following:

- Adding insulation
- Repairing leaks
- Reducing the time that pumps are on
- Reducing resistance to flow

Insulation of bare hot surfaces can be one of the most effective methods for reducing heat loss. Bare, hot pipes lose heat by means of conduction, convection, and radiation. The addition of insulation will considerably reduce such losses, and the savings usually pay for the cost of the insulation in a short period of time.

Many types of insulation are available, including plastics, glass wool, and plastic magnesia. Some insulation comes in the form of tape which can be wound around piping. Other types of insulation are plastered on wet and allowed to dry. Whatever type of insulation is chosen, it should be capable of withstanding the maximum temperature of the surface.

Insulation should be applied to all heated surfaces, such as in boilers, storage tanks, and pipes. In places where the existing insulation is torn or damaged, the insulation should be replaced.

An estimate of the amount of savings that can be obtained by the insulation of piping may be obtained from data shown in Figure 4. This figure is applicable to 1" piping. It shows heat loss versus temperature for a one-foot length of pipe under different conditions:

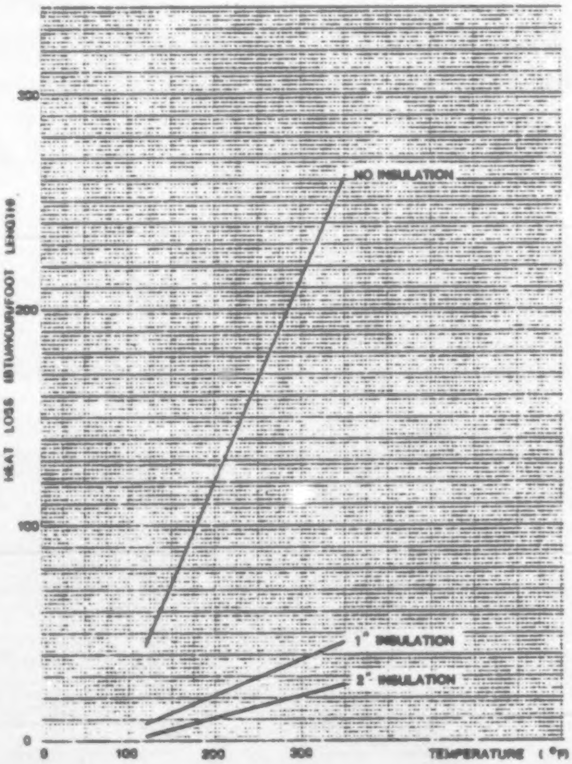


Figure 4. Heat Loss for 1" Pipe.

(1) uninsulated, (2) with one-inch thick insulation, and (3) with two-inch thick insulation. The addition of just one inch of insulation will substantially reduce heat loss.

EXAMPLE C: ENERGY SAVINGS FROM INSULATION OF PIPE.

Given: A section of 1" pipe 100-feet long supplies steam at 250°F for industrial processing. The system is operated two shifts (16 hours) per day for 250 days per year.

Find: The annual energy savings of adding one-inch thick insulation to the pipe.

Solution: The insulation would reduce the heat loss per foot from 170 Btu/hr to 28 Btu/hr, a savings of 142 Btu/hr/ft. For the 100-foot length, this amounts to 14,200 Btu/hr. For a year, the savings would be:

$$14{,}200 \times 16 \times 250 - 5.68 \times 10^7 \text{ Btu}$$

At an energy cost of $\$4/10^6$ Btu, this amounts to \$227.20 savings/yr.

Repair of leaks is a good method of saving energy. There can be leaks at pipe joints and fittings and leaks from valves such as air vents and pressure relief valves. A leak in the system wastes energy by releasing hot water and steam and, thus, losing the energy that heated the water or steam. A leak also increases the load on the pumps and increases the energy required to operate the pumps. Most leaks can be detected by visual inspection of the distribution system; therefore inspections should be conducted periodically.

Another method that helps to reduce the needless use of energy is to reduce the amount of time that the pumps are operated. If pumps operate continuously to circulate water or steam – even when the building is not occupied – energy is wasted.

Consider a factory that has pumps that circulate 300 gallons of hot water per minute, with a head of 70 feet. The factory is occupied 16 hours per day, 365 days per year. If the pumps were turned off for the 8 hours per day that the factory is not occupied, it would save the following amount (using Equation 5):

$$9.1 \times 10^{-7} \times 70 \times 300 \times 8 \times 365 = 55.8 \times 10^{6} \text{ Btu/yr.}$$

Another cause of energy loss can be attributed to excessive resistance to flow. This resistance increases the load on the pumps and leads to excessive energy usage by the pumps. Flow should be kept unobstructed, keeping resistance low. Possible causes of excessive resistance to flow are clogged filters and faulty or sticking valves. The system should be checked periodically to ensure that faulty components that produce excessive resistance to the flow of water or steam are replaced.

Deposits of scale in pipes, heat exchangers, and other locations can also increase resistance to flow by narrowing the size of the flow channel. A periodic check for buildup of scale and a chemical cleaning (if it is necessary) should be standard procedure for reducing resistance to flow.

INCREASING THE EFFICIENCY OF THE SYSTEM

There are additional measures that can be undertaken to reduce energy usage in a steam or hot water system. These measures involve increasing the efficiency of the system, using the following methods:

- Replacing the central system with separate units
- Using a separate boiler in summer

Sometimes the needs for hot water or steam in a building are concentrated at a few locations in the building. In this case, it may be more efficient to have several small hot water or steam generators located close to the places where the water or steam is actually used. This may be preferable since the use of a single large boiler with long runs of piping to deliver the hot water or steam involves considerable energy losses through conduction, convection, and radiation.

The first steps should involve an analysis of the amount of usage of hot water and steam and a determination of where the demand is located. The energy losses of the current system, including losses in the piping, should then be estimated and compared to the savings that would be obtained by installing separate smaller units near the points of usage. Then, the potential savings can be compared to the cost of installing the separate units in order to determine if it would be economical to install them.

In buildings having a heating system that also supplies heat for the hot water or steam, there is an additional method of increasing efficiency. In winter, the boiler may operate at high efficiency, providing both space heat and hot water or steam. But in the summer, the boiler may be oversized, and thereby operate at low efficiency when it is supplying only hot water or steam. In such cases, a separate, smaller boiler for summer usage could be the answer to improving efficiency. Again, an estimate of the potential savings can be compared to the cost of the new boiler in order to determine economic feasibility.

MEASUREMENT DEVICES

There are three quantities that can be measured in hot water and steam distributions: the temperature, pressure, and flow. In practice, however, most installed hot water and steam distribution systems contain relatively few instrumentation devices.

Hot water systems often have a temperature measuring device at the position where the water leaves the boiler. In many cases, this is the only monitoring device contained in the system. Occasionally, systems contain pressure measuring devices located upstream and downstream from filters to monitor the clogging of these filters.

There are several temperature measuring devices available, including thermocouples and bimetallic strips. For a review of the principles of operation of these devices, refer to Module 10T3 in the physics course entitled Unified Technical Concepts III. Commonly, temperature is measured with a thermometer that is in contact with the outside of the pipe. Portions of the system in which the flow is blocked will have a low temperature.

In steam systems, there usually is a pressure gauge located at or near the boiler. This is necessary as a safety precaution, as well as to diagnose system operation. Often, the temperature of the steam is measured as it leaves the boiler.

The efficiency of the distribution system can be defined as "the heat that reaches the point of use, divided by the heat delivered to the fluid at the boiler." For hot water systems, the heat is proportional to the increase in temperature above the ambient temperature. Thus, efficiency may be defined as follows:

$$\frac{T_u - T_o}{T_B - T_o} \qquad \text{Equation 7}$$

where:

T_u = The temperature of the water at the point of use.

T_B = The temperature of the water as it leaves the boiler.

T_o = The ambient temperature.

Thus, one may measure the efficiency of a hot water distribution system simply by measurements of temperature.

Measurement of the efficiency of a steam distribution system is more complicated since part of the energy carried by the steam involves the heat of vaporization of the steam. If the steam at the point of use is wet, or is partly recondensed, then part of that heat of vaporization has been lost. Thus, a measurement of efficiency in a steam distribution system becomes more complicated in that it requires a measurement of the wetness of the steam to determine what fraction has recondensed.

EXERCISES

1. A steel bar that is two feet long has a square cross section six inches on a side. One end of the bar is in contact with ice water at 32°F. The other end of the bar is in contact with boiling water at 212°F. How much heat flows down the rod per hour? (Hint: Use Table 1.)
2. A thin flat plate area that is one square foot has an emissivity of 0.25 and a temperature of 500°F. How much heat is radiated from the plate in Btus per hour? Remember that the plate has two sides.
3. A one-inch diameter pipe 50 feet long carries water at 200°F. The pipe is uninsulated. How many Btus per hour are lost from the pipe?
4. Define the terms "conduction," "convection," and "radiation."

LABORATORY MATERIALS

Surface temperature thermometer (Model HH-2 digital thermocouple meter from Omega Engineering, Inc., or a similar thermometer)

Insulation for covering pipe (should be at least one inch thick)

LABORATORY PROCEDURES

In these procedures, the student will prepare an energy survey for a hot water or steam distribution system in a particular building. The student will also make temperature measurements related to the effectiveness of insulation on piping (in the distribution and on the temperature).

The student must have access to the hot water or steam distribution system in a particular building. A building with a large central system (school, office, factory, and so forth) is preferable. The authorities of the school where this course is presented may be cooperative in providing access to the hot water or steam distribution system. If no other building is available, the domestic hot water system in a private home could be used, but this not the preferred approach.

1. Carry out an energy survey of the steam or hot water distribution system. Use the form and checklist in the Data Table section. Do not be concerned if it is difficult to locate all the information. Building maintenance personnel may be helpful in locating some of the items.
2. Measure the effect of insulation for reducing the temperature of the piping surface. With the system in operation, measure the temperature of the surface of a pipe in the system. Then wrap the surface of the pipe with insulation to a thickness at least one inch. Wait long enough for the temperature to come to equilibrium. Then re-measure the surface temperature at the surface of the insulation. What does the result imply with respect to possible energy savings?
3. Measure the loss in temperature from a source of hot water to the point where it is used. Use the surface

measuring thermometer to measure the temperature T_B of the pipe as it leaves the boiler. Then measure the temperature T_u at the point where the hot water is used. How much does the temperature decrease as the fluid passes through the distribution system? Calculate the efficiency of the distribution system.

$$\text{Efficiency} = \frac{T_u - T_o}{T_B - T_o}$$

In the above, T_o is the ambient temperature. If it is feasible, wrap insulation around the sections of piping leading from the boiler to the point of use. Wait long enough for the system to come to equilibrium. Then re-measure the efficiency.

4. At a point where there is a valve in the system, with the valve open, measure the temperature upstream and downstream from the valve. Close the valve and wait long enough for the system to come to equilibrium. Then re-measure the temperature upstream and downsteam from the valve. What do the results imply with respect to locating blockages of flow?
5. (Optional). Some hot water and steam distribution systems may have pressure or flow meters incorporated as part of the system. Use this existing instrumentation to measure pressure and flow in the system, as appropriate to the specific systems.

DATA TABLES

DATA TABLE 1. ENERGY SURVEY FOR STEAM AND HOT WATER SUPPLY SYSTEM.

Building Size (Square Feet) ____________

Types of Occupancy (% or Square Feet)

Office ____________
Warehouse ____________
Manufacturing ____________
Retail ____________
Lobbies or Mall ____________
Other ____________

Building Use and Occupancy

Fully occupied (50% or more of normal)

Weekdays (hours) _____ to _____
Weekends (hours) _____ to _____
_____ to _____ Sundays
_____ to _____ Holidays

Steam and Hot Water Use (Percent)

Space heating ____________
Domestic uses (handwashing, dishwashing, etc. ____________
Industrial process heat ____________

Capacity

Steam system (gallons per minute) ____________
Hot water system (gallons per minute) ____________

DATA TABLE 2. STEAM AND HOT WATER SUPPLY SYSTEM CHECKLIST.

Yes	No		
☐	☐	1.	Are the exterior surfaces of boilers and storage tanks insulated?
☐	☐	2.	Are the pipes for steam and hot water flow insulated?
☐	☐	3.	Are valve bodies, fittings and other pipe appurtenances insulated?
☐	☐	4.	Is the insulation thick enough so that the outer surface does not exceed 90°F when the system is operating at full load?
☐	☐	5.	Have steam traps passing steam along with condensate been repaired or replaced?
☐	☐	6.	Have any leaks in pipes, pipe joints, or pressure relief valves been sealed?
☐	☐	7.	Has the water temperature been reduced for uses which do not need the highest water temperature?
☐	☐	8.	Have spray type water faucets that reduce water usage been installed?
☐	☐	9.	Have pressure reducing valves been installed in steam lines which do not need the highest pressure?
☐	☐	10.	Has a separate small heater for summer use been installed if the space heating system is used for hot water or steam generation?
☐	☐	11.	Are the circulating pumps turned off during periods when no hot water flow is needed?
☐	☐	12.	Are restrictions to flow in the system removed so as to reduce pump load?
☐	☐	13.	Have the pumps and valves been checked for proper functioning?
☐	☐	14.	Has torn or worn insulation been replaced?

REFERENCE

ASHRAE Handbook, 1977 Fundamentals. New York: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1977. Chapter 2.

Baron, S.L. Manual of Energy Saving in Existing Buildings and Plants, Vol. II, Facility Modifications. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1978. Chapter 2.

Jennings, B.H. Environmental Engineering. Scranton, PA: International Textbook Co., 1970. Chapters 7 and 8.

Strock C., and Koral, R.L. Handbook of Air Conditioning, Heating and Ventilating. New York: Industrial Press, Inc., 1965. Chapter 8.

TEST

1. A steam pipe is at a temperature of 340.3°F. If the temperature is reduced to 213°F, the amount of energy radiated by the pipe will be reduced to about ...
   a. three-fourths of its original valve.
   b. five-eighths of its original valve.
   c. one-half of its original valve.
   d. one-third of its original valve.
2. An aluminum alloy bar is 20 feet long and has a circular cross section two inches in diameter. One end is in a furnace at 800°F; the other end is in contact with ice water at 32°F. The heat flow down the length of the rod – in Btu/hr – is approximately ...
   a. 35.7.
   b. 67.8.
   c. 107.2.
   d. 119.5.
3. A one-inch diameter pipe 30 feet long carries steam at a temperature of 300°F. About how many Btus per hour can be saved by adding two inches of insulation to this section of pipe?
   a. 6
   b. 60
   c. 600
   d. 6000
4. How many Btus per hour are radiated by one square inch of a surface covered with lampblack (emissivity = 0.99) at a temperature of 540.3°F?
   a. 11.3
   b. 44.8
   c. 113
   d. 448

5. Conduction is flow heat through a material because of ________________ ________________.

6. Convection is transfer of heat by __________ __________ __________ __________.

7. Radiation is transfer of heat in the form of ______________________ ____________________.

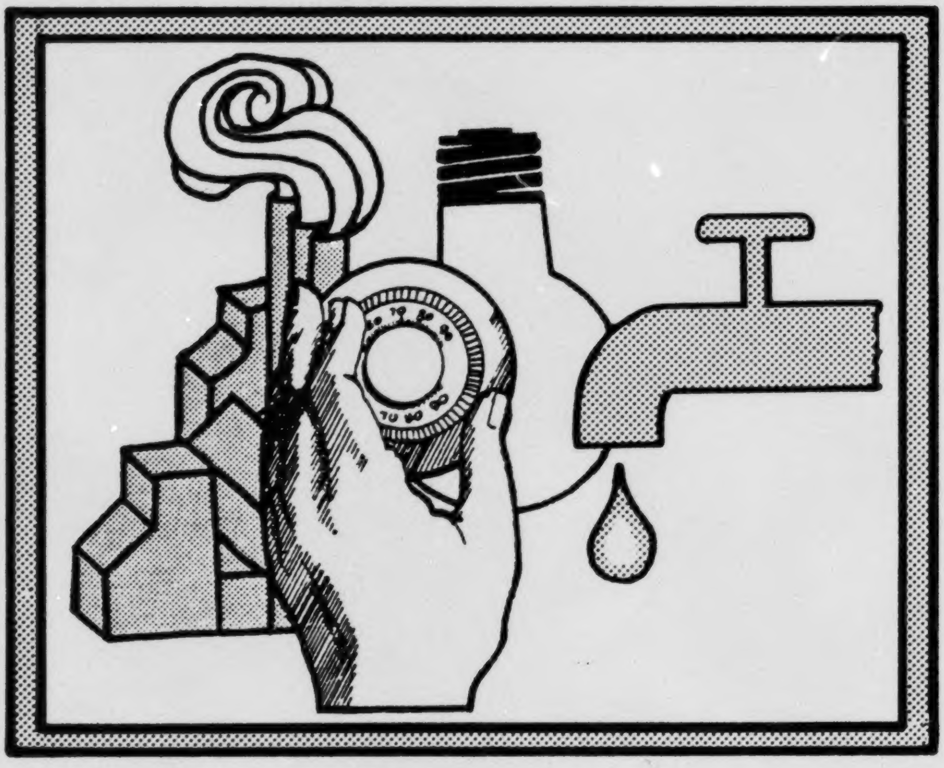
8. Causes of pressure loss include ____________________ in components and ________________ of pumps or valves. Causes of flow loss include ____________________ in components, loss of ________________, ________________ flow control components, faulty ________________, and clogged ____________________.

9. Methods of reducing energy consumption in hot water and steam systems include the following:
   a. Reducing consumption by reduction of the __________, lowering the ______________, and supply of hot water or steam at no more than the required ______________ for most applications.
   b. Reducing losses by adding ______________, repairing ______________, reducing the time that ___________ are on and reducing ________________ to flow.
   c. Increasing efficiency by replacing the ___________ ______________ with ____________ _____________, and using a separate ______________ in summer.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-05

CONSERVATION PRINCIPLES AND EFFICIENCY MEASUREMENTS - ILLUMINATION

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This course describes many ways to conserve electrical power used for illumination. Economic benefits of each method are presented. The units of measurement for illumination are defined, and the use of lighting standards and the operation and use of the light meter are described.

PREREQUISITES

The student should have a basic understanding of algebra and physics and should have completed Modules EC-01 through EC-04 of Energy Conservation.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the terms "lumen" and "footcandle."
2. Calculate illumination levels expected in representative situations of interior lighting.
3. Name the types of lamps described in the module and give their relative efficiencies.
4. Describe methods for saving energy in the use of illumination.
5. Perform calculations on the energy use for lighting. Calculate the projected savings from energy conservation practices.
6. Describe the operation of the light meter.
7. Use a light meter to measure illumination levels.

8. Conduct an energy survey for illumination in a particular building.

CONSEQUENCES OF OVERILLUMINATION

In the past, illumination engineers often specified very high levels of illumination; however, most adhere now to the practice of reducing lighting levels. Of course there will always be some minimum lighting level needed for accurate work performance, and for safety, but, lighting that is far in excess of this level is wasteful of energy.

Overillumination primarily wastes energy because some of the electrical energy that was used to produce the light was unnecessary. A large fraction of the total energy bill for a building is a result of providing illumination, and it makes sense that a reduction of lighting levels will lead to considerable savings of electricity.

In addition, unnecessary heat from the lights in a building may add to the cooling load, thereby wasting energy. Although it may be assumed that lights contribute some heat to the building during the winter, much of it actually escapes through the ceiling since light fixtures are located high in the room near the ceiling and heat rises. Thus, instead of using extra lights to add heat in the winter months, it would be more efficient to reduce the lighting and add more heat by means of the conventional heating system. And, it is also more efficient not to use extra lighting during the cooling season since this, too, increases the use of energy.

LIGHT SOURCES

Light sources used for illuminating purposes emit radiant power, that is, power in the form of electromagnetic radiation. Some of the power represents visible light, which is useful illumination; but some of the power is in the form of infrared or ultraviolet radiation, which is not useful for illumination.

A branch of measurement technology called photometry considers the measurement of light intensity as it relates to illumination. The units that express the levels of illumination are called photometric units. Photometric units are explained as follows:

In photometry, one considers the measurement of light in the visible part of the spectrum only. Because the human eye does not respond equally to all wavelengths, the response of the eye plays an important role in photometry. A red light may emit the same power (in watts) as a green light, but the green light will appear brighter to the eye than the red light, a phenomenon caused by the eye being more sensitive to the green light than to the red light.

The relative sensitivity of the eye as a function of wavelength is called the luminous efficiency. The luminous efficiency versus wavelengths shown plotted in Figure 1 reaches a peak value of one at 555 nanometers (nm) in the green, and falls to low values at the red and violet ends of the visible spectrum. Outside the visible spectrum, the luminous efficiency is zero.

The light source emits radiation at a variety of wavelengths in the visible, infrared, and ultraviolet portions of the spectrum. The total radiation power at all wavelengths may be expressed in terms of the familiar units of watts (W); but the photometer power useful for illumination is expressed in a less familiar unit called the lumen (lm). The lumen may be defined by its relation to radiant power for a particular wavelength, as shown by Equation 1:

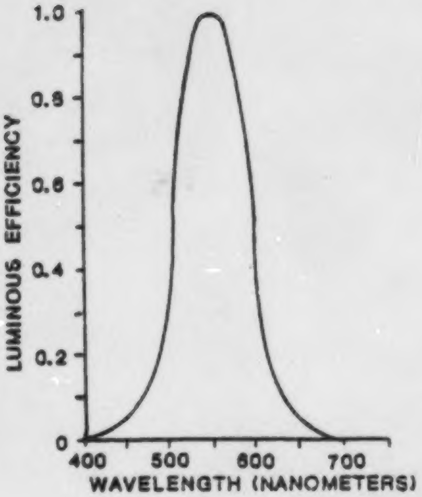


Figure 1. Luminous Efficiency vs. Wavelength.

$$E_p = K_o \times Y \times E_R \qquad \text{Equation 1}$$

where:

E_R = Radiant power, in W.

K_o = A constant, equal to 680 lm/W.

Y = Luminous efficiency, from Figure 1.

Thus, at the peak of the response of the eye at 555 nm, 1 W of radiant power is equivalent to 680 lm of photometric power.

EXAMPLE A: LUMINUOUS POWER OF AN ARGON ION LASER.

Given:	An argon ion laser operating at a wavelength of 514.5 nm emits 10 W.
Find:	The luminous power.
Solution:	At 514.5 nm, $Y = 0.59$. Thus, the luminous power E_ℓ is —

$$
\begin{aligned}
E_\ell &= 680 \times 0.59 \times 10 \\
&= 4{,}012 \text{ lm.}
\end{aligned}
$$

EXAMPLE B: LUMINOUS POWER OF A NEODYMIUM LASER.

Given:	A neodymium laser operating at 1.06 μm emits 1,000 W.
Find:	The luminous power.
Solution:	At 1.06 μm, the luminous efficiency is zero. Thus, the luminous power is 0 lm.

Examples A and B show that, for a monochromatic (single-wavelength) light source, it is easy to convert from radiant power (expressed in watts) to luminous power (expressed in lumens). The conversion is more difficult for other light sources that produce an output over a range of wavelengths. This type of conversion requires the methods of integral calculus, which is beyond the scope of this module. Later, a tabulation will be presented for the conversion from watts to lumens for some common light sources used for illumination.

Lighting levels are commonly expressed in terms of a parameter called illuminance. Illuminance is defined as "the luminous power per unit area."

The unit that is often used for illuminance is the footcandle (fc). One footcandle is equal to an illuminance of one lumen per square foot. The lighting levels in buildings are often specified and measured in terms of footcandles.

A variety of different light sources are commonly used for illumination in homes, offices, schools, factories, parking lots, and so on. This module specifically discusses the following types of light sources:

- Incandescent lamps
- Fluorescent lamps
- Mercury arc lamps
- Sodium vapor lamps

INCANDESCENT LAMPS

Incandescent lamps produce light through thermal vibration of the molecules in a heated metal filament. The filament, which is usually formed from a coil of tungsten metal, is heated by the electrical current that flows through it. It is contained in a glass bulb that is filled with an inert gas so the filament does not burn.

Incandescent lamps emit a continuous spectrum of radiation. The exact distribution depends on the temperature of the filament, but much of the radiation falls in the infrared portion of the spectrum. Figure 2 shows a typical distribution for a household incandescent bulb. Only a relatively small part of the radiant energy falls in the visible spectrum. The remainder falls in the infrared and ultraviolet

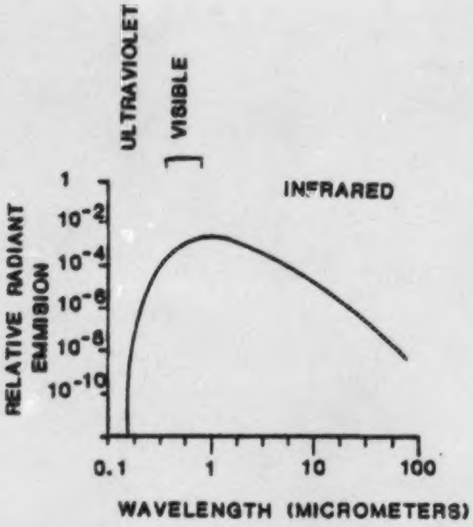


Figure 2. Typical Distribution of Radiant Energy From a Filament in a Household Incandescent Lamp.

spectrum and is useless for purposes of illumination; however, it does add to the heat load.

An incandescent lamp eventually darkens and gives less light as the tungsten evaporates and coats the inside of the bulb. A modern design uses iodine vapor inside the bulb. The iodine combines chemically with the tungsten on the bulb. The tungsten-iodine compound returns to the region of the filament where it is decomposed by heat. The tungsten is then redeposited on the filament — which extends the lifetime of the bulb and minimizes the darkening of the bulb. Lamps of this design are called tungsten-halide lamps.

FLUORESCENT LAMPS

Fluorescent lamps, which are usually glass tubes, may be either straight or curved. They are coated on the inside with a fluorescent powder. Electrodes are at each end of the tube, and the tube is filled with a low pressure of an inert gas with a small amount of mercury added. An electrical current flows through the gas. The mercury vapor in the tube, excited by the electrical current, produces ultraviolet radiation.

The ultraviolet radiation is absorbed by fluorescent powder. This converts the energy into visible light. The fluorescent powder, called a phosphor, consists of a mixture of chemicals that can emit visible light after absorbing ultraviolet radiation. Since many different types of phosphor are used, they produce fluorescent lamps with different characteristics. Figure 3 shows a spectrum from a fluorescent lamp that is called a "cool-white" lamp. The shape of the curve may be varied by the use of different chemicals in the phosphor. Other types of spectra from fluorescent lamps are referred to as "white," "warm-white," and "daylight." The distribution of colors are different in the different types of fluorescent lamps. They are also used for different purposes. For

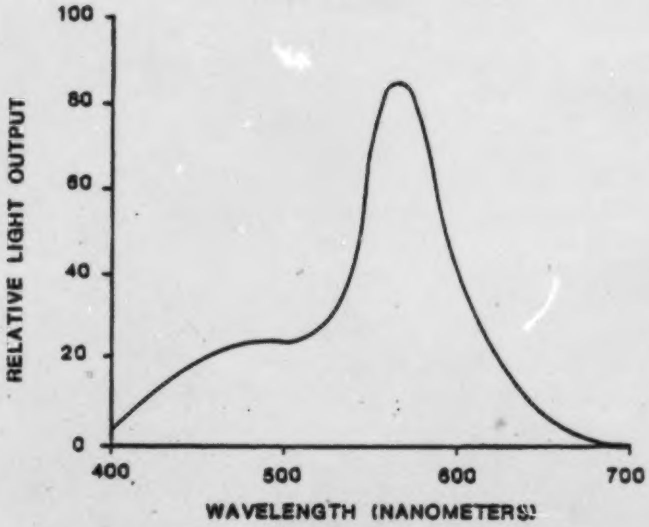


Figure 3. Spectrum of Light From a "Cool-White" Fluorescent Lamp.

example, "warm-white" fluorescent lights are widely used for home lighting because they make human complexions look favorable. "Cool-white" lamps, which are somewhat deficient in red light, are used in conditions where color rendition is not too important. "White" fluorescent lamps are used for general lighting in officies, schools, food stores, and so forth. "Daylight" fluorescent lamps are also used for general lighting. The spectrum of the fluorescent light, as illustrated by Figure 3, contains most of its emission in the visible spectrum. Thus, the fluorescent lamp is more efficient in producing luminous power than the incandescent lamp.

Electrical circuits for fluorescent lamps must provide high voltages to start the lamps. The circuits contain a ballast, which provides the starting voltage and which also limits the current through the lamp.

MERCURY ARC LAMPS

A third type of light source is the mercury arc lamp, which contains mercury vapor at high pressure. An electrical current flows through this gas. The high pressure gas, which can support a large current per unit area, produces a small, highly intense light source.

The spectral output of the mercury arc lamp is concentrated near several distinct wavelengths in the ultraviolet spectrum and in the blue and green portions of the visible spectrum. Thus, the light from mercury arc lamps has a distinct blue-green appearance. Mercury arc lamps usually are not used in homes or offices because their effect on colors is sometimes undesirable. Red objects appear black or brown, for example. However, mercury arc lamps can be used in locations where visual perception of colors is less important, such as parking lots or highways.

A variation of the mercury lamp is the metal-halide lamp, which contains small quantities of an iodide of some other metal in addition to the basic mercury. These lamps offer improved color and increased output compared to a lamp that uses mercury alone.

SODIUM VAPOR LAMPS

The fourth type of light source to be discussed is the sodium vapor lamp. Electrical current is passed through a tube that contains the vapor of the element sodium. Energy is absorbed by sodium atoms and is re-emitted as visible light. The spectral emission shows separate lines at specific wavelengths, with relatively little emission at other wavelengths.

The spectral lines of the sodium vapor lamp are concentrated in the yellow part of the visible spectrum, giving the light a distinctly yellowish appearance which some people find unpleasant. In addition, color rendition is poor with this type of light. For these reasons, sodium vapor lamps are not used in homes or offices, but they are used for lighting of parking lots and roadways.

EFFICIENCIES OF LAMPS

The efficiencies of these lamps for producing luminous power vary according to lamp construction and operating conditions. Table 1 presents some typical values for the efficiencies of the lamps for producing luminous power useful for illumination. These values vary, depending on the exact conditions; but they do allow a comparison of the relative efficiency of the lamps. Incandescent lamps are the least efficient of the lamps discussed; sodium vapor lamps are the most efficient. Because of considerations of the color of the light, usually only incandescent lamps and fluorescent lamps are used for general lighting in homes, schools, offices, and so forth. Of these two lamps, however, the fluorescent lamp is considerably more efficient in converting electrical power into luminous power.

TABLE 1. TYPICAL EFFICIENCIES OF VARIOUS LAMPS.

Lamp Type	Output (lm/W)
Incandescent	20
Fluorescent	60
Mercury Arc	43
Mercury Arc (Metal-halide type)	70
Sodium Vapor	95

For applications where color perception is not important, mercury arc lamps or sodium vapor lamps should be considered. The metal-halide variety of mercury arc lamps offers better color rendition and higher efficiency than the conventional mercury arc lamp. Because they are more expensive than ordinary mercury arc lamps though, the choice depends on a trade-off between the initial cost and the operating cost.

It is important to note that mercury lamps and sodium lamps require a few minutes before they reach maximum brightness, whereas incandescent lamps and fluorescent lamps turn on almost instantly. This fact restricts the use of mercury or sodium lamps in some cases.

Lamps used for illumination are mounted in fixtures. The design of the fixture strongly influences the illumination that can be obtained. Reflectors at the top of the fixture help direct the light downward. Diffusers made of translucent plastic at the bottom of the fixture can provide more illumination and reduce glare. Fixtures designed for commercial and industrial use emphasize features of low maintenance, efficiency, and durability.

The illuminance that can be expected in a room may be estimated from Equation 2.

$$E = N\ F\ K\ M/A \qquad \text{Equation 2}$$

where:

E = Illuminance, in fc.
N = Number of light fixtures.

F = Luminous power emitted from each fixture, in lm.

K = Coefficient of utilization.

M = Maintenance factor.

A = Area of the room, in ft^2.

The coefficient of utilization depends on the shape and design of the light fixture and the reflector. It also depends on the shape of the room and on the reflectance of the ceiling, walls, and floor. It is beyond the scope of this module to tabulate the values of the coefficient of utilization versus all the variables on which they depend; however, these tabulations, which are used by illumination engineers, are available in handbooks. For the purposes of this module, it can be noted that values of the coefficient of utilization increase as the reflectances of the walls and ceiling increase. And these values are higher for lamp fixtures which direct most of the light downward. For reasonable cases, values of coefficient of utilization that fall in the range of 0.4 to 0.7 are typical.

The factor M, called the maintenance factor, is a number less than one. It accounts for the collection of dust and dirt on lamps, relfectors, and diffusers, as well as for the darkening of lamps as they age. A clean fixture with new lamps will have a maintenance factor approximately equal to one.

EXAMPLE C: CALCULATION OF ILLUMINANCE.

Given: A 10' x 12' room has two light fixtures, each containing two 100-W fluorescent lamps. The lamps are new and the fixtures are clean. A tabulation in a handbook on illumination gives 0.69 as the coefficient of utilization for this particular combination of lamps and room.

Find: Estimate the illuminance.

Solution: Use Table 1 to estimate the lamp output. Each lamp produces 60 x 100 = 6,000 lm. Each fixture produces 12,000 lm. The area of the room is 120 ft^2. The maintenance factor is approximately one. Thus, the illuminance is —

$$E = \frac{2 \times 12{,}000 \times 0.69 \times 1}{120}$$

$$= 138 \text{ fc.}$$

ENERGY SURVEY FOR ILLUMINATION

An audit of energy use relative to illumination is an important first step for energy conservation related to illumination in a specific building. This survey is similar to surveys conducted in earlier modules for heating, cooling, and hot water distribution. A suggested format for an energy survey relative to illumination is provided in the Data Tables section, which also contains a checklist of practices in lighting usage. The checklist highlights some of the possible ways to save energy used for illumination. Later, the student will prepare an energy survey for illumination in a building.

ENERGY CONSERVATION METHODS FOR ILLUMINATION

The following discussion describes methods that can be used to reduce the use of energy for illumination. Some of these methods include the following:

- Reducing illumination levels
- Improving lighting facilities
- Changing lamp type
- Changing lighting patterns
- Using waste heat from lighting

REDUCING ILLUMINATION LEVELS

In the past, lighting standards were often specified by the manufacturers of light bulbs. These specifications tend to be too generous today since energy is much more scarce and expensive. Most of these earlier standards are now being re-evaluated.

Table 2 presents some suggested levels of illuminance for various types of use. These levels are not the official standards of any group since there does not appear to be any widely accepted standard for illuminance at the present time. Rather, the levels suggested in Table 2 are a compilation of a number of unofficial recommendations. Earlier standards which suggest higher levels of illuminance are still in use, but substantial energy savings would be possible if everyone would establish a policy of reducing their standards of illumination. This can be easily accomplished by simply changing to lamps of a lower wattage than those that are currently being used. Or, it may be accomplished by removing some of the lamps in multi-lamp fixtures. But, the

TABLE 2. SUGGESTED LEVELS OF ILLUMINANCE.

Type of Use	Lighting Level (Footcandles)
Office Buildings	
Regular office work	70
Detailed drawing, designing, etc.	100+
Stairways, corridors	20
Conference rooms	30
Washrooms, toilets	20
Schools	
Stairs, corridors	20
Classrooms	70
Factories	
Ordinary assembly and inspection	50
Very difficult inspection or very fine assembly	200+
Locker rooms, washrooms	20
Cafeterias	50
Stores	
Circulation areas	30
Ordinary merchandising areas	100
Special showcases and displays	200+
Parking Lots and Roadways	2-5

light levels should be measured, and they should not be reduced below levels needed for safety and for proper work performance.

Selectivity is an important factor in the reduction of of light levels. If lighting is fairly uniform in a building, illumination can be reduced much more in the corridors than in the office or factory assembly areas, as Table 2 suggests.

Furthermore, the values of illuminance should be determined at the area where the work is being done. For example, the light level in an office should be specified at the desk top. And, too, the determination should allow for the fact that light levels become lower with time because of lamp darkening and dirt collection. For instance, if 70 footcandles are desired, and it is expected that lamp darkening and dirt will reduce light levels by 12.5% over a period of a few months, then the initial level of new lamps and clean fixtures should be set at 80 footcandles.

EXAMPLE D: REDUCTION OF ILLUMINATION.

Given: A large office building uses 1,000 fluorescent lamps, each having a 200-W rating. The illuminance at the desk tops is 100 footcandles.

Find: The energy that can be saved if 300 lamps are removed, reducing the illuminance to 70 footcandles. Assume the lamps are on for 3,000 hr/yr.

Solution: The savings are as follows:

$$300 \text{ lamps} \times 200 \text{ W/lamp} \times 3{,}000 \text{ hr}$$
$$= 18 \times 10^7 \text{ Wh} = 18 \times 10^4 \text{ kWh}$$

At 4¢/kWh, this amounts to an annual dollar savings of $7,200.

IMPROVING LIGHTING FACILITIES

There are numerous ways in which improvements can be made to facilities to increase lighting efficiencies.

As previously mentioned, the light output of lamps decreases with time because of lamp darkening and also because of dirt that collects on lamps, reflectors, diffusers, and so forth. Figure 4 shows the decrease in lamp output versus time for three lamp types. For example, after about 10,000 hours of operation, the output of fluorescent lamps has decreased to about 80% of the original value. A program of replacing lamps when their output has dropped can save energy. The savings are offset by the cost of the new lamps, of course, but it usually is economical to replace lamps when their output has dropped to about 75% of the original value.

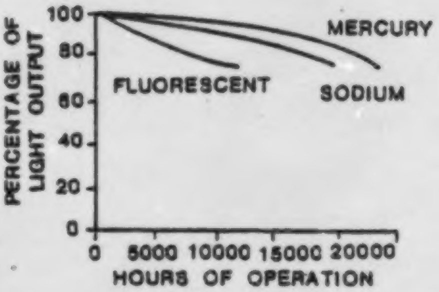


Figure 4. Decrease of Lamp Output vs. Time.

The decrease in light output due to accumulation of dirt and dust on the lamps and fixtures in varying environments is illustrated in Figure 5. The environments range from clean to very dirty. Even for a clean environment, light output decreases more than 15% over a two-year period; but when lamps and fixtures are kept relatively clean, fewer lamps are needed to provide the same level of illuminance — which, of course, leads to energy savings. Therefore, a program that includes lamp and fixture cleaning should be an integral part of any energy conservation effort.

The coefficient of illumination depends on the type of fixture being used. For a given number of lamps, the illumination depends on the amount of light transmitted into the space by the fixture. The shape of the reflector and the transmittance of the diffuser (used to reduce glare) can change the amount of useful light that reaches the work area. Thus, current fixtures that have a low coefficient of utilization should be replaced with more efficient fixtures, thereby allowing fewer lamps to provide the same illumination.

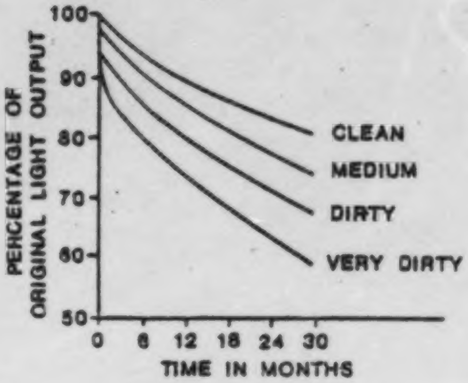


Figure 5. Decrease of Light Output vs. Time in Various Environments.

However, replacement of a large number of lighting fixtures can be expensive. The potential energy savings must be compared to the cost of fixture replacement in order to determine if the replacement is economically justified.

Another consideration of facility improvement includes installation of automatic switching. Automatic switching can ensure that lights are out at times when the building is not in use. A program of this type could provide relatively high illumination during working hours, lower illumination in the early evening when maintenance workers are doing their jobs, and even lower illumination at night. However, some illumination may still be needed for the safety of night guards.

Still another method of facility improvement involves redecoration and repainting. Brighter, more reflective colors increase the coefficient of utilization as a result of wall surfaces and ceilings becoming more reflective. This also permits the use of lower wattage lamps, or even the removal of some lamps, without reducing levels of illumination.

CHANGING LAMP TYPE

The efficiency of a lighting system may be improved by changing to a more efficient type of lamp. See Table 1 for an approximate summary of lamp efficiencies. In some cases, a change from incandescent lamps to fluorescent lamps can produce increased lamp efficiency. The savings from increased efficiency must be analyzed, however, and compared to the cost of changing the lamps and adding different fixtures. But, because the efficiency of fluorescent lamps is much greater than that of incandescent lamps, the change may often be economically justified.

The replacement of fluorescent lamps with metal-halide lamps or sodium vapor lamps could yield even greater energy savings. However, since there are limitations in color rendition with such lamps, the change may not be appropriate. Metal-halide lamps and sodium lamps are normally best suited to applications such as the illumination of parking lots.

EXAMPLE E: REPLACEMENT OF BULBS.

Given: A store is now using 66 incandescent light bulbs that have a 500-W rating. These bulbs have an efficiency of 20 lm/W.

Find: The effect of replacing these bulbs with 28 metal-halide bulbs that have a 400-W rating and an efficiency of 58 lm/W. The lights are on 3,700 hr/yr.

Solution: The current number of lumens is 66 x 500 x 20 = 660,000 lm. This will be reduced to 649,600 lm by the replacement – a reduction of approximately 1.6%.

The total energy usage now is –

66 x 500 x 3,700 = 122,100,000 Wh/yr
= 122,100 kWh/yr

This would be reduced to –

28 x 400 x 3,700 = 41,440,000 Wh/yr
= 41,440 kWh/yr

This is a savings of more than 66% in energy use. The savings in kilowatt hours per year is 80,660 kWh. At a cost for electrical energy of 4.2¢/kWh, this amounts to $3,388/yr.

CHANGING LIGHTING PATTERNS

A simple method of saving energy for lighting is to turn out the lights when they are not in use. Yet, as simple as this may seem, people continue to leave lights on even when it is unnecessary. Control of lighting can take various forms, but the goal remains the same: Lights should be on only when necessary and only in necessary places. Lighting patterns can be placed under the control of a computerized building automation system. These can provide the following:

- Easy adjustment of light levels to changing job requirements.
- Variable lighting patterns in different parts of the building that have different schedules.
- Automatic compensation for the availability of natural illumination (sunlight).
- Ability to include lighting control in programs for reducing peak electrical demand.
- Ability to use task lighting — that is, higher illumination for those specific tasks that need it and on the specific schedule for those tasks.

Another changeable pattern allows for the improved use of natural light (sunlight). Skylights can be used to provide additional light to supplement or replace artifical light. Reflectors may be installed near windows to increase the amount of daylight entering the building. If these methods are used, they should be analyzed carefully to ensure that the additional energy entering the building does not increase the load on the cooling system to a degree that is uneconomical.

Finally, work stations may be moved and rearranged. Those tasks that need the highest light level should be placed in locations where the light level is high. And, they should be grouped together so that they can all be well lighted. Then the light levels in other areas where tasks are being performed that do not require such high light levels may be reduced.

EXAMPLE F: ALTERATION OF LIGHTING PATTERNS.

Given: An office building uses 280 kW of fluorescent lighting. Lights are left on from 7 a.m. until 11 p.m. (when the janitors leave) for five days a week.

Find: How much could be saved by operating the lights from 7 a.m. until 5 p.m. without reduction, and then reducing the lighting to 140 kW from 5 p.m. until 11 p.m. for maintenance work only.

Solution: The savings would be –

$$140 \text{ kW} \times 30 \text{ hr/wk} \times 52 \text{ wk/yr} = 218{,}400 \text{ kWh/yr.}$$

USING WASTE HEAT FROM LIGHTING

The heat from light fixtures can add to the cooling load in the summer. In winter, light fixtures can add some desirable heat, but much of the heat is lost. For example, loss through false ceilings can remove this heat from the occupied parts of the building.

However, light fixtures are available which can return some of the warm air to the room. In addition, there are ventilation systems which can return the hot air above the false ceilings back into the room. In the summer, the warmer air could be vented to the outside.

The cost for the installation of such a system is likely to be expensive; therefore, it may not be economically justified. The best time to consider such changes might be at a time when major building modifications are being performed.

MEASUREMENT OF ILLUMINANCE

Measurement of illuminance is accomplished with a device called a photometer, also commonly called a light meter.

Earlier instruments used for the measurement of illuminance compared the brightness of a diffuse surface. The brightness of the same surface was compared visually to the brightness of the same surface illuminated by a calibrated light source. The measurement was cumbersome and tedious.

Modern light meters use the photovoltaic effect. When light falls on a semiconductor material (such as selenium or silicon), it releases free electrons inside the semiconductor. Under certain conditions, the electrons will flow as electrical current in a circuit. A meter in the circuit registers the current flow. The current increases as light intensity increases; thus, measurement of the current provides a direct measurement of the light intensity.

One of the device configurations that can produce current flow through the action of the photovoltaic effect is sketched in Figure 6. Light falling on the selenium layer produces a current flow that can be measured by the meter. Materials other than selenium can be used (for example, silicon); however, the device construction is somewhat different. A complete description of the photovoltaic effect is presented in Module 10E3 of Unified Technical Concepts III.

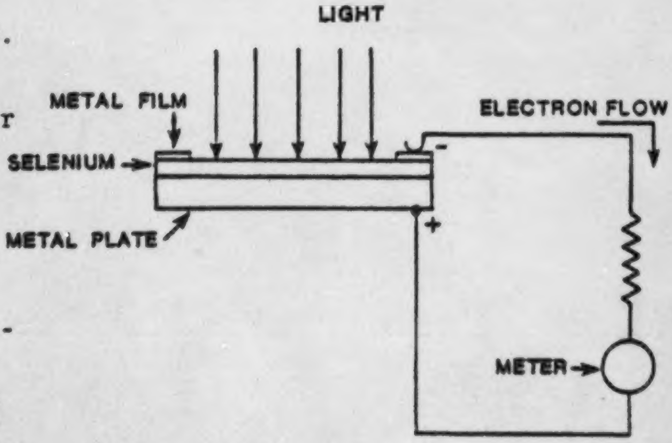


Figure 6. Schematic of Light Meter Based on Photovoltaic Effect.

Such photovoltaic cells generate a current of approxmately six to seven microamperes per footcandle of visible light falling on them. For circuits with low resistance, the current can be directly proportional to the light intensity.

The response of the device should be similar to that of the human eye. Thus, current output versus wavelength should have the shape of the curve shown in Figure 1. High quality meters have a corrected response that approximates the response of the human eye. The meter can then be calibrated directly in footcandles.

Small, portable light meters based on the photoelectric effect are now available. These light meters, which have a direct readout in footcandles, are very similar to exposure meters used in photography, except that exposure meters have their calibrations in terms of camera aperture stops. The availability of portable photoelectric light meters makes it relatively simple to monitor the illuminance levels inside buildings.

EXERCISES

1. Define lumen. Define footcandle.
2. Suppose that a 13' x 16' room has two lamp fixtures, each containing six 150-W incandescent light bulbs. The lamp fixtures and the room have a coefficient of utilization of 0.5 and a maintenance factor of 0.8. What is the expected illuminance?
3. Name the types of lamps described in the module. Which is most efficient? Which is least efficient?
4. Describe the methods listed in the module for saving energy in illumination.
5. An office building uses 600 incandescent light bulbs, each having a 100-W rating. How many lumens do these lamps produce? If electricity costs 4.3¢ per kilowatt hour, how much will it cost to operate the lights for 2,500 hours per year? If the lamps were replaced by fluorescent lamps with 100-W ratings, how many lamps would be needed to give the same number of lumens? What would be the annual savings for 2,500 hours of operation?
6. Describe the operation of a light meter.

LABORATORY PROCEDURES

The student will prepare an energy survey for illumination in a particular building. The student must have access to some building. A building such as an office, school, or factory is preferred. The authorities of the school where this course is offered may be cooperative in providing building access. If no other building is available, a private home could be used.

Perform an energy survey of the illumination in the building. Use the form and checklist provided in the Data Table section. Do not be concerned if it is difficult to find all the information. Building maintenance personnel may be helpful in locating some of the items.

Next, the student will measure illuminance levels in the building, using a light meter. The light meter to be used should be portable, but it should be of good quality. Some of the least expensive models of light meters cannot be relied upon for measurements of high accuracy. The meter should be color-corrected so as to have a response similar to that of the human eye. It should also be of a type called cosine low-corrected (or Lambert's low-corrected). These meters have special shapes on the cover to avoid problems with reflection of light from the surface. A suitable photometer with a digital readout is model 450, manufactured by EG & G, Inc., Salem, Massachusetts.

Use the light meter to measure illuminance levels in a number of different areas in the building. Include as many different areas as possible, such as classrooms, assembly areas, inspection areas, library reading rooms and card file areas, storage areas, boiler rooms, office areas, cafeterias, gymnasiums, lobbies, corridors, stairwells, locker rooms, washroons, and so forth. Measure the light intensity at different positions in the rooms: near the floor, at the desk top, near the ceiling, and so on. If possible, turn off a fraction of the lights and repeat the measurements.

Compare the results of these measurements to the recommended lighting levels given in Table 2. Generate recommendations for possible energy conservation in lighting in these areas, based on the results of the measurements just performed.

DATA TABLE 1. ENERGY SURVEY FOR ILLUMINATION (TOTAL SQUARE FEET).

TYPE(S) OF OCCUPANCY: (% OR SQ. FT.)

Office ____________ (Other) ____________
Warehouse ____________ (Other) ____________
Manufacturing ____________ (Other) ____________
Retail ____________
Lobbies & Mall (Enclosed) ____________

BUILDING USE AND OCCUPANCY

Fully Occupied: (50% or more of normal)
Weekdays (Hours) ________ to ________
Weekends (Hours) ________ to ________
________ to ________ Sunday
________ to ________ Holidays

Remarks: Describe below if occupancy differs for different floors, areas, buildings:
____
____
____

LIGHTING SURVEY

1. Interior Lighting Type ____________ Footcandles Offices ________
________ Other ____________
Total Install KW ____________
On-Off from Breaker Panel? ____________
Wall Switches? ____________ Control Switching? ________
Operating Schedule ____________
____

2. Exterior Lighting Type ____________ Sq. Ft. Served: ________
Total KW ____________ Footcandles: ____________

Remarks: ____________________________________
____

Operating Schedule: ____________________________________
____
____

DATA TABLE 2. CHECK LIST FOR LIGHTING.

Yes	No	
☐	☐	Are two-level lighting and switching provided to permit reduction in lighting during use and no-use periods?
☐	☐	Is daylight used for illumination whenever possible?
☐	☐	Have the light intensities been reduced consistent with safety and work needs?
☐	☐	Are lenses and reflectors clean?
☐	☐	Are the light fixtures and reflectors of types that are consistent with high efficiency?
☐	☐	Have you considered a possible increase in lighting effectiveness by proper spacing and arrangement of the fixtures?
☐	☐	Have you considered change of lamp type for improved efficiency?

REFERENCES

IES Lighting Handbook. New York: Illuminating Engineering Society.

Manual of Energy Saving in Existing Buildings and Plants. Baron, S.L., Ed. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1978. Chapter 7.

Marks' Standard Handbook for Mechancial Engineers. 8th ed. Baumeister, Theodore, Ed. New York: McGraw-Haill Book Co., 1978. pp 12-116 to 12-135. (This reference presents tabulations of the coefficient of utilization.)

TEST

1. At a wavelength of ____________________ nanometers, the conversion of radiant power to luminous power may be expressed as ______________ lumens per watt. At other wavelenths, the luminous power is reduced by the luminous efficiency of the _______________. A footcandle is equal to ______________ ______________ ______________ ______________ ______________.

2. A 30' x 15' room has four clean light fixtures, each containing four new 100-W incandescent lights. The coefficient of utilization may be assumed to be 0.71. The expected illuminance in the room, in footcandles, is ...
   a. 50.5
   b. 60.6
   c. 70.7
   d. 80.8

3. The types of light sources discussed in the text are the _______________ lamp, the _______________ lamp, the ______________ ______________ lamp, and the ______________ ______________ lamp. Of these, the least efficient for producing luminous power is the ______________ lamp, and the most efficient is the ______________ ______________ lamp.

4. Energy for lighting may be reduced by reducing __________ levels, improving lighting ______________, changing ______________ type, changing lighting _____________, and using waste _____________ from lighting.

5. A device for measuring levels of illuminance is called a _____________ _____________. Modern, portable, devices use the _______________ effect.

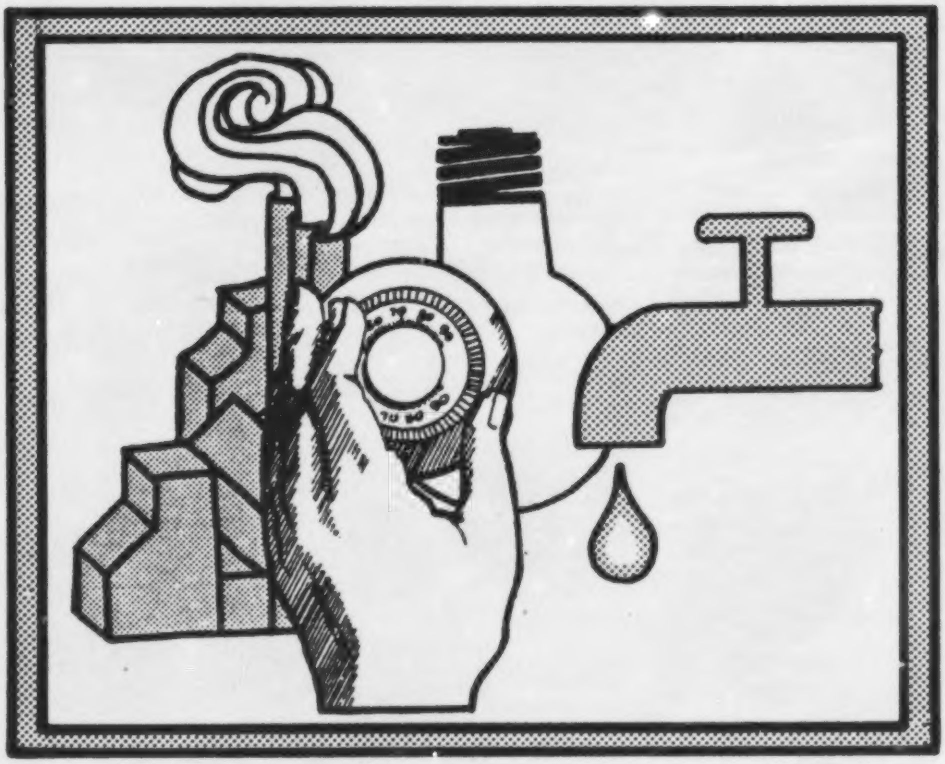
6. A parking lot is lighted by 20 mercury arc lamps with a rating of 1,000 W each. These lamps operate at an efficiency of 50 lm/W. How many sodium vapor lamps, with 500-W ratings and efficiencies of 100 lm/W, would be needed to replace the mercury arc lamps and give the same light level?
   a. 5
   b. 10
   c. 20
   d. 40

7. If the lights in the example above are on for 1,000 hr/yr, how many kilowatt hours per year would be saved by changing from mercury to sodium lamps?
   a. 5×10^5
   b. 10^6
   c. 5×10^6
   d. None of the above

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-06

CONSERVATION PRINCIPLES AND EFFICIENCY MEASUREMENTS - ELECTRIC MOTORS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module discusses methods of conserving electrical power in the use of electric motors. It also describes general methods for managing the electrical power load in a building in order to conserve energy.

PREREQUISITES

The student should have a basic understanding of algebra, physics, and trigonometry and should have completed Modules EC-01 through EC-05 of Energy Conservation.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the term "power factor." Discuss the consequences of low power factor. Discuss methods to improve power factor.
2. Define the terms "actual power", "apparent power", and "reactive power."
3. Perform calculations related to power factor, actual power, apparent power, and reactive power.
4. Describe operational procedures that can be used to increase the electrical efficiency of electric motors.
5. Describe equipment improvements that can be made by the operator of an electric motor to increase its efficiency.

6. Describe maintenance and inspection procedures that can be used to increase the efficiency of electric motors.
7. Describe methods for managing the electrical power load in a building in order to conserve energy.
8. Perform an energy survey on the use of electric motors and management of electrical power in a specific building.
9. Measure the power factor and the efficiency of an electric motor.

AN INTRODUCTION TO CONSERVATION OF ELECTRICAL POWER

Since use of electrical power is a major contributor to the total energy consumption of a building, the cost of providing this electrical power constitutes a major portion of the expense involved in operating a building. Thus, the reduction of electrical power consumption contributes to both energy conservation and cost reduction.

A major portion of the discussion in this module concerns energy conservation practices that concern electric motors since electric motors are one of the largest users of electrical energy in most facilities. For this reason, they are an important concern in any program implemented to conserve electrical energy. Conservation practices described in this module not only apply to electric motors, they also apply to other types of electrical equipment.

Electrical power is also consumed by electric lights and by equipment such as the blowers and fans in heating, ventilating, and air conditioning systems, chillers in cooling systems, and pumps in hot water or steam distribution systems. However, energy conservation practices relative to these components were described in earlier modules and will not be included in this module.

In addition to electric motors, this module includes a discussion on electric load management. There are many practices for reducing energy consumption that include scheduling and load management. An important area to consider is the improvement of power factor, which is described in the next section.

POWER CONSUMPTION

The concept of power factor in an a.c. electrical distribution system must be considered because the current and voltage in the a.c. system are not always inphase. Both voltage and current vary as sine waves. Figure 1 shows voltage and current when they are inphase. In Figure 1, the peaks of the sine waves for the two quantities occur at the same time, and the positions where the sine waves pass through zero occur at the same time. The value of power at any time is the product of current and voltage at that time. Thus, the power appears as it is shown in the bottom part of Figure 1. The power never dips below zero to a negative value.

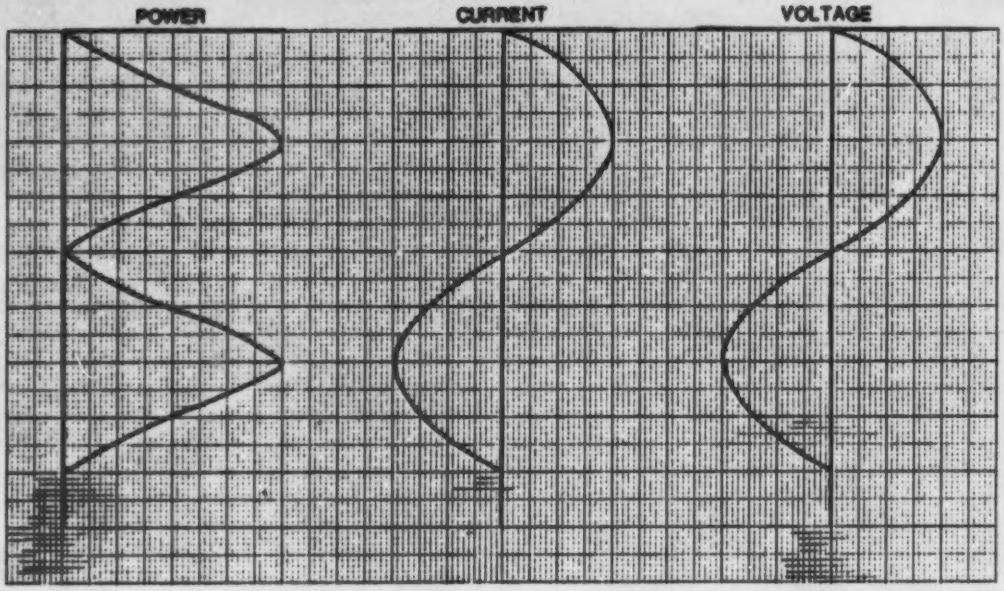


Figure 1. Relation of Power Components in an A.C. System with Current and Voltage Inphase.

However, in practical systems in large installations, the current and voltage will almost never be exactly inphase. This situation is shown in Figure 2. The peaks of the sine waves, as well as the zeroes, occur at different times for the two quantities. The difference is indicated by the angular difference ϕ. (Remember that the total angular cycle of a sine wave is 360°.) Again, the value of power at any time is the product of current and voltage at that time. The current and voltage are sometimes opposite in sign; thus, the power flow is sometimes negative, as indicated in the lower part of Figure 2.

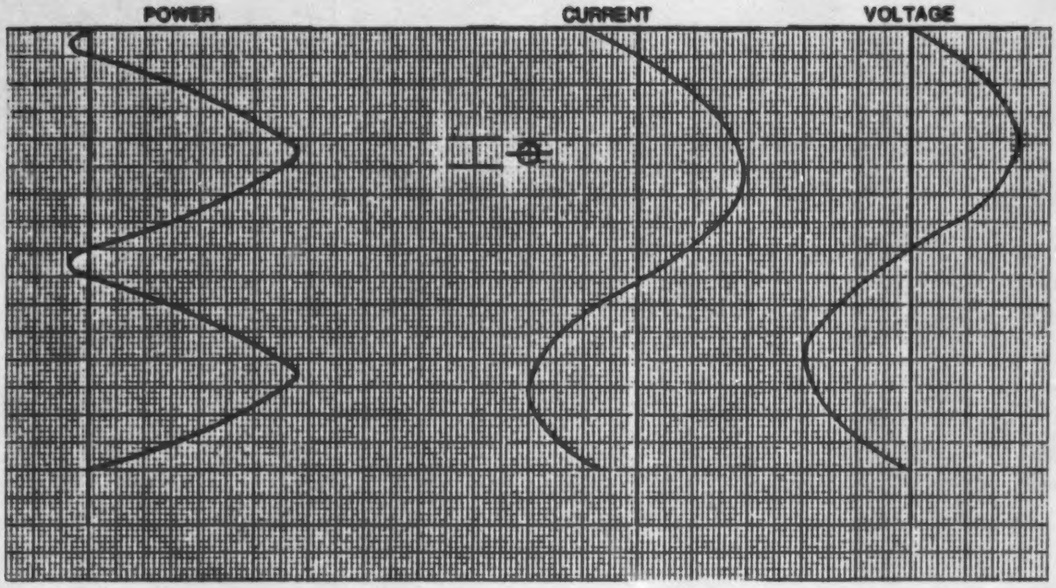


Figure 2. Relation of Power Components in an A.C. System with Current and Voltage not Inphase.

The negative component of power must be subtracted from the positive component in order to give the actual power used. The positive component can be regarded as power extracted from the distribution system, and the negative component can be regarded as power returned from the load to the distribution system.

The phase of the current usually will be behind the voltage inphase, as is indicated in Figure 2. (In rare cases, the phase of the current may be ahead of the voltage.) The inphase difference of the current and voltage is the result of adding current-consuming loads (such as electric motors) to the system.

At this point, several terms relevant to power consumption should be defined: actual power, apparent power, reactive power, and power factor.

ACTUAL POWER

Actual power is the power consumed by the load. It is a measure of the energy consumption per unit time, measured by the watt-hour meter and expressed in kilowatt-hours. If the current and voltage are inphase (Figure 1), the actual power essentially is given by the product of voltage and current. If the current and voltage are now inphase (Figure 2), then the actual power is the positive component minus the negative component of power. The actual power must be measured by the watt-hour meter.

APPARENT POWER

Apparent power is obtained by multiplying the current and voltage. Thus, apparent power is measured in units of kilovolt-amperes (KVA). In a single-phase system, apparent power is given by Equation 1:

$$KVA = EI/1000 \qquad \text{Equation 1}$$

where:

KVA = Apparent power rating.
E = Voltage, expressed in volts.
I = Current, expressed in amperes.

In a three-phase system, apparent power is given by Equation 2:

$$KVA = 1.73\ EI/1000 \qquad \text{Equation 2}$$

REACTIVE POWER

In an alternating current system, the electrical current may be considered as being composed of two components, one inphase with the voltage, and one lagging behind it (or in rare cases, leading it) by 90°. This situation is illustrated in Figure 3.

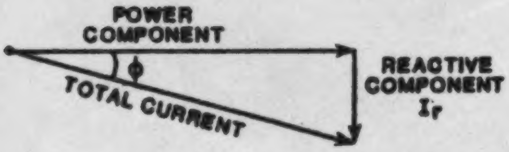


Figure 3. Relation of Power Component and Reactive Component of Current in A.C. Circuit.

The inphase current is called the power component. The out-of-phase component is called the reactive component (denoted by I_r). The angle ϕ between the total current and the power component is the same angle ϕ that expresses the phase difference between the voltage and the current. The reactive power is defined as "the product of the voltage E and the reactive current I_r." The reactive power in a single-phase system is given by Equation 3:

$$VAR = E \cdot I_r \qquad \text{Equation 3}$$

where:

VAR = Volt-amperes reactive.

E = Voltage.

I_r = Reactive component.

In a three-phase system, the reactive power is given by Equation 4:

$$VAR = 1.73\ E \cdot I_r \qquad \text{Equation 4}$$

The reactive power, VAR, is expressed in terms of volt-amperes. The total energy consumption is expressed in terms of VARH, volt-ampere reactive-hours (or KVARH, kilovolt-ampere reactive-hours).

POWER FACTOR

Power factor, often expressed as PF, is given by the ratio of apparent power to actual power (Equation 5):

$$PF = \text{Actual power/apparent power} \qquad \text{Equation 5}$$

Power factor may also be expressed as follows (Equation 6):

$$PF = \cos \phi \qquad \text{Equation 6}$$

where:

ϕ = Angle between the power component of current and the total current in the vector diagram of Figure 3.

It is also the angle by which the current and voltage are out-of-phase (Figure 2).

The definition of power factor may be given by either Equation 5 or Equation 6; both definitions are equivalent.

EXAMPLE A: CALCULATION OF POWER FACTOR AND ACTUAL POWER.

Given:	In a building, the current lags the voltage by 30°, and the apparent power usage is 10,000 KVA.
Find:	The power factor and the actual power.
Solution:	The phase angle ϕ is 30°. According to Equation 6, the power factor is:

$$PF = \cos 30^\circ = 0.866.$$

According to Equation 5:

$$\begin{aligned}\text{Actual power} &= \text{PF x apparent power}\\ &= 10{,}000 \times 0.866\\ &= 8{,}660 \text{ kW.}\end{aligned}$$

EFFECTS OF LOW POWER

Low power factor is undesirable. The capacity of electric power lines, generators, transformers, and other components is usually limited by heating effects. The heating, in turn, is caused by current flow. Thus, there is a maximum current flow which can be permitted without overheating occuring. Because the power factor is equal to the power in kilowatts divided by the apparent power in KVA, a low power factor means that the KVA must increase in order to maintain the same power. This means that more current must flow, and there will be more problems with heating.

Alternatively, if the current is kept within proper limits to avoid overheating, the KVA will be limited. Then the actual power will be kept below the rated circuit value if the power factor is low.

The effect on the electric utility that generates the power is the following: the low power factor overloads generating and distribution networks with excess KVA. Thus, electric utility companies monitor the power factor of large users of electricity. They require that the power factor be kept above some value (perhaps in the range of 0.9 to 0.95). If the power factor is not maintained above the required level, the utility imposes an extra monetary charge on the user. (Note: this applies only to large users.) The power factor usually is not monitored for small users, such as homes and small commercial buildings. In summary, the effects of low power factor on the user can be the following:

- Power overheating for a fixed actual power
- Operation of equipment below rated power levels
- Extra charges by the electric utility

MEASUREMENT OF POWER

There is no simple meter that measures power factor directly. The usual method is to measure two sides of the power triangle shown in Figure 4.

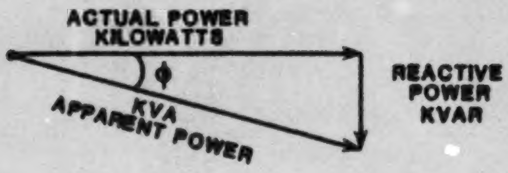


Figure 4. Power Triangle.

The triangle shows the relationship among actual power, apparent power, and reactive power, with the phase angle ϕ also indicated. (This is a right triangle; and if the measurements of two sides of a right triangle are given, trigonometry may be used to derive the measurement of the third side.) Thus, measurements of two of the three quantities in the power triangle will allow determination of the third quantity.

EXAMPLE B: CALCULATION OF ACTUAL POWER, POWER FACTOR, AND PHASE ANGLE ϕ BETWEEN CURRENT AND VOLTAGE.

Given: In a building, reactive power is 3 KVAR and apparent power is 9.8 KVA.

Find: The actual power, the power factor, and the phase angle ϕ between current and voltage.

Example B. Continued.

Solution: According to trigonometry, in a right triangle with sides a, b, and c (with c the hypotenuse), $a^2 + b^2 = c^2$. In this case, a, b, and c will be identified as actual power, reactive power, and apparent power, respectively. Thus, actual power is given by:

$$\text{Actual power} = \sqrt{(\text{Apparent power})^2 - (\text{Reactive power})^2}$$

$$= \sqrt{9.8^2 - 3^2} = 9.33 \text{ kilowatts.}$$

The power factor is:

$$\text{PF} = \text{actual power/apparent power}$$

$$= \frac{9.33}{9.8}$$

$$= 0.952.$$

The phase angle ϕ is:

$$\phi = \text{arc cos } 0.952$$

$$= 17.8^\circ.$$

These quantities are measured by the following methods.

1. Apparent power is determined by measurement of the voltage and current separately, using a.c. voltmeters and ammeters. After these measurements are made, apparent power is calculated from Equation 1 for a single-phase system and from Equation 2 for a three-phase system. In a three-phase system, the current used in Equation 2 should be the average of the currents measured in each of three phases.

2. Actual power is measured with a wattmeter. The wattmeter may take a number of forms, but the most common form uses two coils of wire. One coil, which is constructed of course wire, is fixed and is connected in series with the electrical load. The second coil. constructed of fine wire, can rotate under the action of torque applied to it and is connected across the source of supply voltage. The current flowing in the fine wire coil induces a torque that moves the coil and, thus, deflects a needle attached to it. Because of its inertia, the coil does not follow the rapid oscillations of the a.c. voltage. Rather, it assumes a deflected position that depends on the average (actual) power. The motion of the coil is opposed by a spring that returns the meter to zero when the electricity is off. The description of the wattmeter given above is applicable to a single-phase system. Polyphase wattmeters are also available. These contain two wattmeter mechanisms attached to a common shaft. It is possible to measure the power in a three-phase system with a single instrument constructed in this fashion.
3. Reactive power generally is not measured directly by individual users, so the instrumentation used will not be discussed in detail. Instrumentation involving phase-shifting transformers may be used by electric utility companies to measure the reactive power for large users. Such instrumentation may be referred to as a KVAR meter.

CORRECTION OF LOW POWER FACTOR

Several methods for correcting low power factor include the use of capacitor banks, switched capacitors, and synchronous motors.

Capacitor Banks

Because capacitor banks tend to cause the current to lead the voltage, they may be added to a power distribution system to help correct a low power factor that results from a lagging current. A capacitor bank of the proper size can increase power factor. A value of power factor above 0.95 usually is considered acceptable. Capacitor banks may be installed on either the primary or secondary side of the transformer serving a building. However, the primary side usually is preferred.

Switched Capacitors

Switched capacitors may be desirable in buildings with large, intermittent loads (such as large motors that do not operate continuously). The capacitors are connected to the motors and are in use only when the motors are turned on. Switched capacitors are needed (instead of fixed capacitors) when the capacitors are so large that they cause an undesirable leading current if the motors are turned off.

Synchronous Motors

The use of synchronous motors in place of induction motors can also have a desirable effect on power factor. Since synchronous motors cause the current to lead the voltage (just as capacitors do), they have the same effect as capacitors for increasing power factor. Replacing induction motors with synchronous motors is beneficial in many instances.

ENERGY SURVEY FOR ELECTRIC MOTORS AND ELECTRIC POWER USAGE

A survey (audit) of energy use for electric motors and other applications of electric power is an important first step for energy conservation related to electrical power consumption in a specific building. This survey is similar to the surveys presented in earlier modules for heating, cooling, illumination, and so forth. A suggested format for an energy survey and a checklist of practices relative to electric motors and electric power usage are given in Tables 1 and 2. The checklist highlights some of the ways that energy can be saved in electrical power usage. Later, the student will prepare an energy survey for electrical power usage in a specific building.

TABLE 1. ENERGY SURVEY - ELECTRIC MOTORS AND ELECTRIC POWER USAGE.

Building Survey

Total Square Feet ________

Types of Usage (% or square feet)

- Office ________
- Warehouse ________
- Manufacturing ________
- Retail ________
- Lobbies and Enclosed Mall ________
- Other ________
- Other ________

Electric Power Input

- Total Rated Power ________ Kw
- Total Rated Current ________ Amperes

Equipment List

Item	Equipment Description	Number	Rated Output (Hp or Kw)	Rated Input (Kw)	Operating Schedule
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

TABLE 2. CHECKLIST - ELECTRIC MOTORS AND ELECTRIC POWER USAGE.

Yes	No	
☐	☐	Are manual or automatic controls installed to disconnect loads when they are not required?
☐	☐	Are manual or automatic controls installed to reduce peak loads?
☐	☐	Has the power factor been determined for the building?
☐	☐	Has low power factor been corrected with capacitors or other means?
☐	☐	Have oversized motors been replaced?
☐	☐	Have low voltage systems (120-V) been replaced with higher voltage systems wherever possible?
☐	☐	Have operations been scheduled in order to reduce peak load?
☐	☐	Have motors been located in order to allow efficient heat removal?
☐	☐	Have worn and inefficient motors been replaced?
☐	☐	Is there a regular program for maintenance of electric motors and other electrical equipment?

CONSERVATION IMPROVEMENTS - ELECTRIC MOTORS

This section specifically deals with energy conservation methods and improvements in operation procedures involving electric motors. There are three general approaches that may be undertaken to improve the electrical efficiency of electric motors. The first and second approaches will be dealt with in this module.

The first approach involves improving the operation of the motors. The second approach involves equipment improvements made by the operator of the electric motor in order to increase the efficiency of the motors. The third approach involves efficiency improvements that can be made by the motor equipment manufacturer, such as design factors. However, motor design is a well developed technology; therefore possible improvements in this area are beyond the scope of this module. The operator of the motor should consult the manufacturer's specifications to ensure that an efficient motor is being purchased.

IMPROVEMENT OF OPERATION

Methods for improving operation procedures for electric motors include the following:

- Regular inspection and maintenance
- Control of peak demand by rescheduling
- Selection of continuous production processes

These are all procedural methods. They involve no changes in equipment, but they may involve changes in the procedures for using existing equipment. All three methods can lead to decreases in the cost of electrical power.

Regular Inspection and Maintenance

Regular inspection of the condition of electric motors and maintenance of the motors will ensure that the motors are operating at high efficiency. These procedures will also help reduce breakdowns, repair costs, and downtime. The inspection and maintenance procedures should involve many parts of the motors, such as the brushes, bearings, rotors, and windings.

Brushes should be checked for proper fit and free movement. The brush-spring pressure should be checked. Brushes that are worn or have chipped or damaged faces should be replaced.

Many types of bearings are used on motors, including ball bearings, roller bearings, and sleeve bearings. The housing for the bearings should be checked for leakage of oil or grease and contact surfaces of bearings should be examined. Bearings that show any sign of damage should be replaced. Periodically, old oil or grease in the bearings should be purged and replaced with fresh oil or grease.

Rotors should be checked for loose or broken parts, as well as for any evidence of overheating. The rotors should also be examined for any marks that indicate contact with other structures.

The motor windings should be examined for cracks or other damage in the insulation. The resistance of the insulation can be measured with a voltmeter having a resistance at least 100 ohms per volt.

The surfaces and passages in the motor should be cleaned thoroughly if they show signs of accumulation of dust, dirt, or other foreign matter.

Control of Peak Demand By Rescheduling

The power companies must be able to satisfy the peak demand for electrical power; thus, the increased demand for electrical power requires them to spend more money for the generation of electricity. For one thing, they must construct enough generating plants and equipment to satisfy this peak demand. The cost of constructing a plant is high; yet when the demand for electrical power is lower, the plant or equipment may sit idle. Thus, it is peak demand that influences the electric power companies' construction costs.

In order to apportion the cost of additional equipment and transmission lines, power companies monitor the electrical usage of commercial and industrial customers. Then, they include extra demand charges in the electric bill sent to customers. When electric consumption (measured over a short interval) exceeds a pre-established peak, a new and higher demand charge is applied to the electric bill. Sometimes the demand charge is high, amounting to as much as 30% of the electric bill for a large user.

Thus, it makes sense to control peak demand and smooth out fluctuations that can lead to high peak values of electrical consumption. If electrical power consumption is spread more uniformly throughout the day, it can reduce the peak values. This saves the customer money by reducing the demand charges. The entire community is also affected since this reduces the need to build new plants and equipment for more generating capacity.

Companies that use several large electric motors should analyze their schedule of operation, avoiding periods when all the motors operate at the same time. The schedules for motor operation should be staggered in order to spread the consumption rate more uniformly throughout the work day.

Selection of Continuous Production Processes

There are different ways in which a production process may be established. It may be continuous, with parts moving sequentially and continuously from one operation to another. Or, it may be the batch-type of process with the first operation being performed on an entire batch of parts, then the next operation performed on the entire batch, and on down the line.

Selection of a continuous process can help smooth out fluctuations in the use of electric motors and in the consumption of electric power. This reduces peak demand and the extra demand charges from the electric utility.

It may not always be feasible to select a continuous production process, however. If some other process is already established, it may not be economical to dismantle it for this reason alone. But, when a new process is implemented, this factor should be considered.

Improvement of Equipment

The previous section of the module described procedural methods that save money and electrical energy in the use of electric motors. The methods discussed involved changes in operating procedures but did not involve changes in the equipment itself. The next section describes methods that can be employed by the operator of an electric motor to increase its efficiency. These methods usually involve some change or replacement of equipment; therefore, they may require some initial cost. Again, the most attractive time for these changes to be made may be at a time when changes are also being made for other reasons. These changes may include:

- Changing oversized motors
- Installing higher voltage systems
- Replacing worn or inefficient motors
- Improving heat removal

Changing Oversized Motors

Motors are often too large for the service they perform. This reduces the efficiency of motor operation and also has a harmful effect on power factor. Figure 5 shows motor efficiency and the power factor versus load for a typical induction motor. The load is expressed as a percentage of the full-rated load of the motor. At high loadings (greater than 75%) electric motors can be quite efficient, with efficiencies in the range of 80% to 90%. But at low values of loading, efficiency can drop to a very low value. Similarly, the power factor for a motor is very low at low loading values.

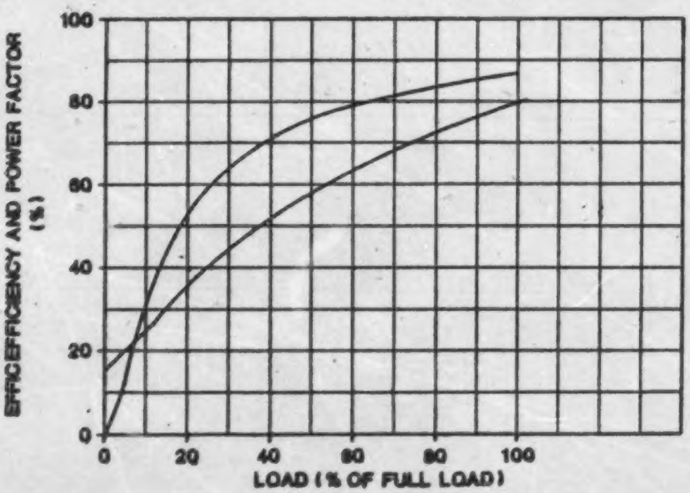


Figure 5. Power Factor and Efficiency Vs. Load for Typical Induction Motor.

Thus, electric motors should always be matched in size to the job they perform for two reasons: an oversized motor wastes electric energy because of low efficiency and it harms the power factor. Oversized motors should be changed and replaced with properly sized motors – preferably, motors that are loaded to 75% or more of their rated value.

Similarly, motors should not be undersized (too small for their load) since this results in the use of excessive current and overheating.

Ideally, the proper time for motor sizing is when new equipment is being ordered. The manufacturer's ratings for the motors should be compared to the demands of the service, and a motor that will be loaded between 75% and 100% of its full rating should be chosen.

Installing Higher Voltage Systems

Although the highest practical voltage that is available should be used, it is not always economically feasible to change existing systems to convert to higher voltage. However, when new equipment is being installed or when major remodeling is being done, higher voltage systems should be chosen. This is particularly true if the total electric service is relatively large (greater than 500 KVA). For instance, 480-V or 240-V systems should be chosen instead of 120-V systems.

Replacing Worn or Inefficient Motors

Old, worn motors waste energy when they operate at low efficiency. As suggested earlier, a program of regular inspection will identify those components that are inefficient due to age, wear, damage, and so forth. Motors that prove to be inefficient should be replaced.

Improving Heat Removal

Motors should be installed so that they have adequate space and air circulation room in order to provide good removal of heat. If motors are crowded or surrounded with other equipment, heat removal may not be effective, leading to overheating and loss of efficiency.

Heat removal can be improved just by repositioning motors and other equipment so that air is allowed to circulate around each motor.

ELECTRICAL POWER MANAGEMENT

Preceding sections have discussed methods to save both electrical energy and money relative to the use of electric motors. The following paragraphs contain a more comprehensive discussion of the management of electrical power consumption in a building. Methods for saving money and energy in this area include:

- De-energizing equipment
- Reducing peak loads
- Improving power factor

DE-ENERGIZING EQUIPMENT

Turning electrical equipment off when it is not in use is the most simple, obvious way to reduce the total electrical energy consumption in a building. The equipment can be turned off with manual switches, but the most efficient method is to use an automatic turn-off apparatus, such as automatic timers. These timers turn equipment off when it is not needed, according to a preset schedule.

An even more efficient method to control the turn-off of electrical equipment is the use of a computer-based system for total building control, including heating, cooling, lighting, and electric motors. This offers the greatest flexibility.

Many pieces of electrical equipment – such as elevators, transformers, water coolers, business machines, electric cooking equipment, and electric heating equipment – are being energized 24 hours a day, 7 days a week, even though they may be in use only about 50 hours per week. This equipment can be de-energized to conserve electrical consumption.

Electric motors, in particular, can offer attractive savings. Large motors account for a major portion of the electric load in many buildings. First, the schedule of usage for electric motors should be analyzed to determine the times they are actually needed; then, they should be de-energized at times when they are not needed.

REDUCING PEAK LOADS

The effect of high peak loads has already been described. High peak loads result in extra demand charges from electric utility companies, and they force utilities to seek new ways of adding generating capacity. Thus, an effort to reduce peaks in electrical demand is important. The process of reducing peak loads is called load limiting, load leveling, or load shedding.

Figure 6 shows a hypothetical pattern of demand in a typical office building during the course of one work day.

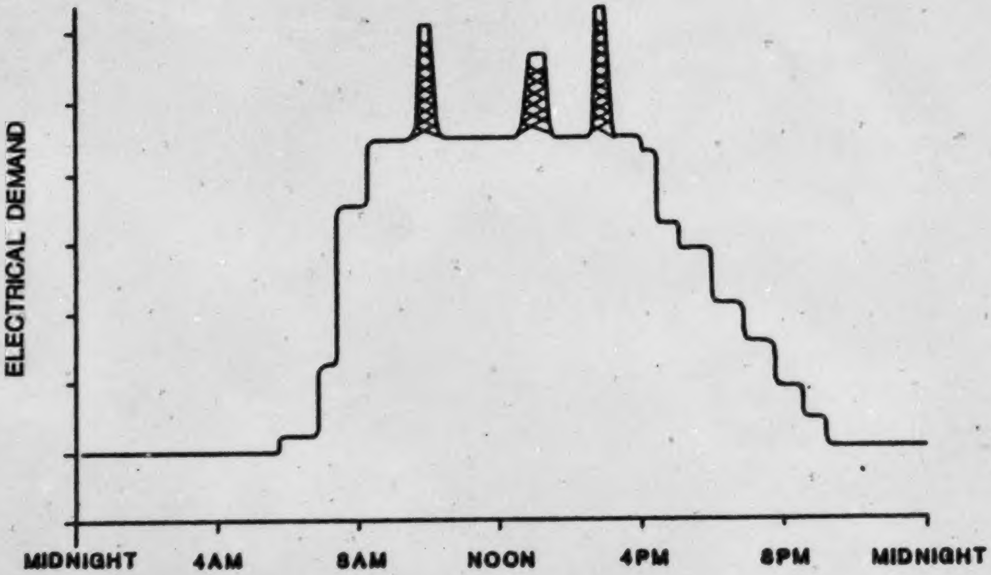


Figure 6. Hypothetical Pattern of Daily Electrical Demand.

The figure shows three high peaks (indicated by hatching) that represent relatively short periods of time during the day when electrical demand is greatest. A reduction of demand at these three times would be very cost effective.

The process of load shedding to reduce peak demand involves turning off selected pieces of equipment when the load rises above a predetermined value. Some pieces of equipment can be turned off for short periods of time without greatly disrupting their function. An example might be electric water heaters. A short period of off-time during periods of high electrical demand can easily be tolerated by water heaters. Another example might be the air conditioning system. This, too, could be turned off briefly without greatly affecting building temperature. As an example, the air conditioner could be switched off when an elevator motor is running.

Some load limiting can be accomplished with manual switching, but this is probably not as effective as automatic switching. If schedules for operating large pieces of equipment can be determined in advance, automatic shut-off of other pieces of equipment can be performed with automatic timers.

Probably the best and most versatile method of load-leveling involves a central control system with a computer. The control system can continuously monitor the electrical demand. It can forecast when demand is rising toward a peak, and start switching off loads before a predetermined level is exceeded. The loads may be turned off according to assigned priorities. A "rolling" basis may be used for turning off loads so that the same load does not always get turned off first.

IMPROVING POWER FACTOR

The effects of low power factor have already been described, including possible extra charges by the electric power companies and a decrease in the useful capacity of the electrical distribution system. For these reasons a complete program for management of the electrical power usage must include correction of possible low power factor.

The electric utility company should be consulted to determine the value of the power factor and the amount of extra charges, if any, that are being assessed because of low power factor. After this information is received, a decision can be made about the advantages of improving the power factor. Methods for improving power factor have already been described. These include installation of capacitor banks, use of switched capacitors, and use of synchronous motors in place of induction motors.

It may not be feasible to replace existing induction motors; yet, when new motors are to be purchased, the power factor should be considered a major factor in selecting the motors. A choice can also be made between capacitor banks located at the main electrical service or switched capacitors associated with specific pieces of equipment. If low power factor is associated with a few specific pieces of equipment, switched capacitors associated with those pieces of equipment would be economical. If there are a number of different loads producing low power factor, and these loads are reasonably constant, then installation of capacitor banks for the entire electrical service can be cost-effective.

EXERCISES

1. Define the term "power factor." Describe the consequences of low power factor. Discuss methods to improve power factor.
2. Define the terms "actual power," "apparent power," and "reactive power."
3. In a factory, three-phase electrical power is supplied at a voltage of 220 volts. The current load is 1600 amperes. The phase of the current lags the voltage. What is the apparent power? What is the power factor? What is the actual power? What is the reactive power?
4. Describe operational procedures that can be used to increase the electrical efficiency of electric motors.
5. Describe equipment improvements that can be made by the operator of an electric motor to increase its efficiency.
6. Describe maintenance and inspection procedures that can be used to increase the efficiency of electric motors.
7. Describe methods for managing the electrical power load in a building in order to conserve energy.

LABORATORY PROCEDURES

1. The student will prepare an energy survey for electrical power usage and electric motor usage in a particular building. The student must have access to some building. A building that uses large amounts of electrical power, such as a factory or large office building is preferred.

It is also desirable to select a facility in which a number of electric motors are in use. There may be several electric motors in office buildings — for example, in HVAC systems and in elevators. Perform an energy survey for the use of electric motors and management of electrical power. Use the form and checklist in Data Tables 1 and 2. Do not be concerned if it is difficult to find all the information. Building maintenance personnel may be helpful in locating some of the items.

2. Next, the student will measure the power factor and efficiency of a motor. In addition, the student will contact the power company to determine building power factor.

   a. Measurement of power factor of a motor.

      In order to measure the power factor, the equipment needed is an a.c. voltmeter, an a.c. ammeter, and a wattmeter. For a single-phase motor, one single-phase wattmeter is needed. For a three-phase motor, a poly-phase wattmeter or two single-phase wattmeters will be needed.

      The apparent power is determined from measurements of the voltage and current. The voltmeter is connected in parallel with the motor and the ammeter in series with it, as indicated in Figure 7. The motor should be under load. Measure the voltage V (in volts) and the current I (in amperes). The apparent power is then given by —

      Apparent power (volt-amperes) = I x V

      for a single-phase system. For a three-phase system, measure the current in each phase of the system.

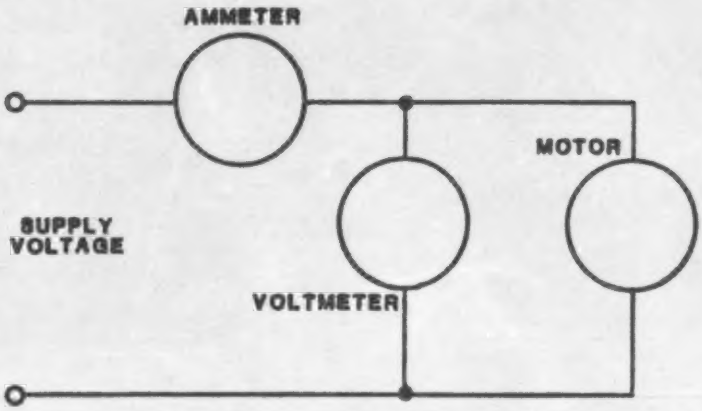


Figure 7. Arrangement for Measurement of Apparent Power.

This will give three values: I_1, I_2, and I_3.

Determine the average current, I ave.

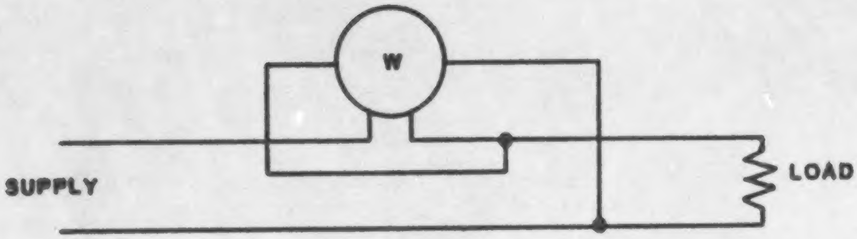
$$I \text{ ave} = (I_1 + I_2 + I_3)/3$$

Then the apparent power is given by –

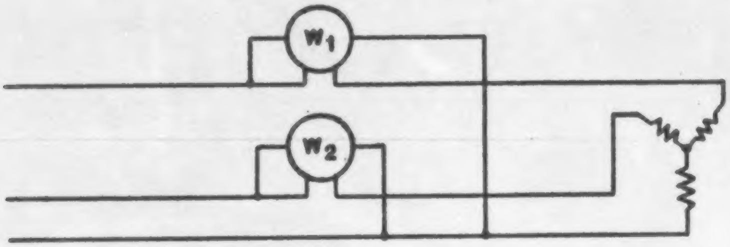
$$\text{Apparent power (volt-amperes)} = 1.73 \text{ I ave} \times V$$

Then, connect the wattmeter, as indicated in Figure 8. The top portion shows the connection for a single-phase system. The bottom part of the figure shows the connection for two single-phase wattmeters in a three-phase system. This bottom part also represents the connection for the individual elements in a poly-phase wattmeter.

With the motor under the same load as for the measurement of apparent power, measure the actual power given by the wattmeter reading (in watts). Then, determine the power factor from the following equation:



a. Single Phase



b. Three Phase

Figure 8. Wattmeter Connection.

$$\text{Power factor} = \frac{\text{apparent power}}{\text{actual power}}$$

b. Measurement of efficiency of a motor.

The efficiency of the motor is the ratio of the output power of the motor to the input electrical power. Preferably, the output power is measured with a dynamometer, a device for measuring the power developed by a motor. In one form, the dynamometer uses conducting disks that rotate in a magnetic field. Essentially, it is an electric generator that is driven by the motor.

Connect the motor so that it drives the dynamometer, and use the dynamometer reading to determine the output power of the motor (in watts).

If a dynamometer is not available, the output power may be measured by using the motor to lift a weight and measuring the rate at which the weight is raised. Set up a system of ropes and pulleys that will allow the motor to raise a known weight W. It may take some experimentation to set up pulleys that will raise the weight and use a stop watch to determine the time t that it takes for the weight to be raised a known distance D. For W (in pounds), D (in feet), and t (in seconds), the output power of the motor is given by –

$$\text{Output power (watts)} = 1.356 \times W D/t$$

Then, use the wattmeter (as described before) to measure the input electrical power (in watts). This measurement should be made under the same conditions of motor loading as the measurement of output power. Then the efficiency is given by –

$$\text{Efficiency} = \text{Output power}/\text{input power}$$

c. Building power factor.

Contact the electrical utility company that supplies electricity to the building for which the energy survey was made. Find out what the building power factor is and what extra charges, if any, are made for low power factor. Then, using these findings as a basis, make a recommendation about whether the building power factor should be improved.

DATA TABLES

DATA TABLE 1. ENERGY SURVEY – ELECTRIC MOTORS AND ELECTRIC POWER USAGE.

Building Survey

Total Square Feet ________

Types of Usage (% or square feet)

Office ______

Warehouse ______

Manufacturing ______

Retail ______

Lobbies and Enclosed Mall ______

Other ______

Other ______

Electric Power Input

Total Rated Power ______ Kw

Total Rated Current ______ Amperes

Equipment List

Item	Equipment Description	Number	Rated Output (Hp or Kw)	Rated Input (Kw)	Operating Schedule
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

DATA TABLE 2. CHECKLIST — ELECTRIC MOTORS AND ELECTRIC POWER USAGE.

Yes	No	
☐	☐	Are manual or automatic controls installed to disconnect loads when they are not required?
☐	☐	Are manual or automatic controls installed to reduce peak loads?
☐	☐	Has the power factor been determined for the building?
☐	☐	Has low power factor been corrected with capacitors or other means?
☐	☐	Have oversized motors been replaced?
☐	☐	Have low voltage systems (120-V) been replaced with higher voltage systems wherever possible?
☐	☐	Have operations been scheduled in order to reduce peak load?
☐	☐	Have motors been located in order to allow efficient heat removal?
☐	☐	Have worn and inefficient motors been replaced?
☐	☐	Is there a regular program for maintenance of electric motors and other electrical equipment?

REFERENCES

Fink, Donald G., Editor-in-Chief. Standard Handbook for Electrical Engineers. New York: McGraw-Hill Book Co., 1968, 10th edition, Section 18.

Baron, Stephen, editor. Manual of Energy Saving in Existing Buildings, and Plants, Volume II, Facility Modifications. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1978, Chapter 8.

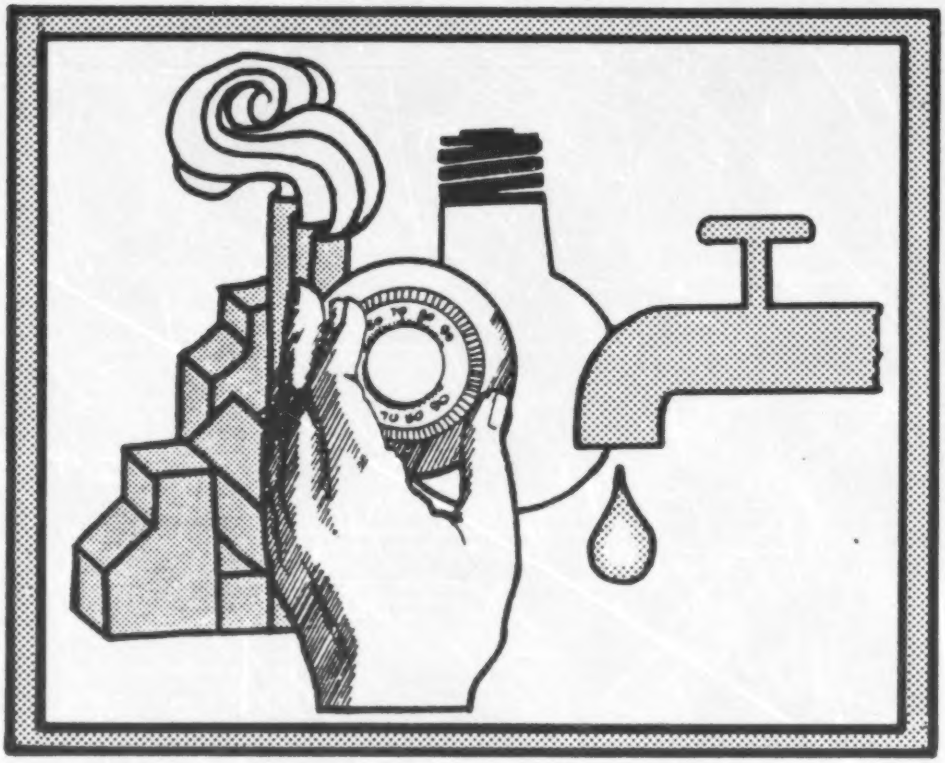
TEST

1. Power factor is defined as the ratio of the __________ power to the __________ power. It is also equal to the __________ of the __________ angle between the a.c. voltage and __________.
2. The __________ power is measured in kilowatts, the __________ power in KVAR, and the __________ power in KVA.
3. If the angle ϕ discussed in the text is 12°, what is the power factor?
   a. 0.978
   b. 0.908
   c. 0.866
   d. 0.208
4. Methods for improvement of operation procedures for electric motors include regular __________ and __________, control of __________ __________ by rescheduling, and selection of __________ production processes.
5. Methods for improvement of motor efficiency include changing __________ motors, installation of higher __________ systems, replacement of __________ or __________ motors, and improvement of __________ __________ removal.
6. Methods for electrical power management in a building include __________ equipment, reducing __________ __________, and improving __________ __________.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY CONSERVATION



MODULE EC-07

CONSERVATION PRINCIPLES AND EFFICIENCY MEASUREMENTS - BUILDING CONSTRUCTION

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module introduces energy conservation techniques relevant to the design and construction of buildings. It describes methods applicable to new buildings such as choice of site, size of furnace, type of construction, and type of materials. It also describes modification of existing buildings by adding insulation, weatherstripping, caulking, and storm windows.

PREREQUISITES

The student should have a basic understanding of algebra and physics and should have completed the course Energy Production Systems and Modules EC-01 through EC-06.

OBJECTIVES

Upon completion of this module the student should be able to:

1. Define the terms "U" and "R" as they are related to thermal transmission.
2. Perform calculations related to thermal transmission in buildings.
3. List design considerations to reduce energy loss in new buildings.
4. List methods for energy conservation in existing buildings by retrofit.
5. List techniques which may be used to determine energy loss from buildings.

6. Describe the following methods for energy conservation in existing buildings:
    a. Methods for control of window loss.
    b. Methods for control of heat loss through walls and ceilings.
    c. Methods for control of infiltration.
7. For various locations within the United States, determine values for R values for insulation.
8. Conduct an energy survey for the construction of a building.
9. Measure the R value for insulation.

SUBJECT MATTER

ENERGY CONSERVATION IN BUILDING CONSTRUCTION

This module introduces energy conservation techniques relevant to the design and construction of buildings. Previous modules in this course have emphasized techniques and practices by which energy may be saved in heating, cooling, and so forth. This module is somewhat different in that it emphasizes materials, such as the effects of insulation, caulking, weatherstripping, and the addition of storm windows. For example, the R values which are used to characterize insulation are defined, and recommended values for R values are presented.

The greatest flexibility and choice of methods is available at the time that a new building is being constructed. The full range of energy-conserving features is available, including choice of site, building orientation, type of construction, choice of materials, and size of the furnace.

Some of these options are not available for existing buildings. Still, the potential for energy-saving modifications is very great. One may add insulation, storm windows, weatherstripping, sheltered entryways, and awnings — as well as other energy-saving devices.

Later in the module, the principles of heat exchange between a building and its surroundings will be described. The specific methods for improving energy loss will be discussed, both for new buildings and for existing buildings. In addition, methods for diagnosing any energy loss in buildings will be presented. The result is a full evaluation of the opportunities for energy conservation in building construction and use.

HEAT EXCHANGE BETWEEN A BUILDING AND ITS SURROUNDINGS

The interchange of heat between a building and its surroundings is governed by the thermal transmission of the building's materials. Thermal transmission coefficients express the rate of heat flow through a structural material. Thermal transmission coefficients are usually represented by the symbol U, and the heat transmission of a structural element is described by the U value for the element. The units for U are not often explicitly stated in discussions of insulation. The units will usually be Btu per square foot per hour per degree Fahrenheit. Unless otherwise stated, U values may be assumed to be in these units. In winter, the direction of heat flow is from the inside of the building to the outside. High heat loss adds to the heating load. In the summer, heat flow is from the outside to the inside, adding to the cooling load. Much of the summer heat gain occurs through the windows. Thus, the discussion of heat flow through other structural elements (walls and roof) will emphasize heat loss in the winter.

The heat loss from a building is given by Equation 1:

$$Q = (U_{wall}A_{wall} + U_{roof}A_{roof} + U_{floor}A_{floor} + U_{window}A_{window} + 0.018W)\Delta T$$

Equation 1

where:

$U_{wall}, U_{roof}, U_{floor}, U_{window}$ = U values for the walls roof, floor, and windows, respectively.

A_{wall}, A_{roof}, A_{floor}, and A_{window} = Areas of the walls, roof, floor, and windows, respectively, in ft^2.

W = Rate of infiltration of outside air into the building, in ft^3/h.

ΔT = Temperature difference between the inside and outside, in °F.

This equation then gives the heat loss from the building, in units of Btu/hour.

The term involving heat loss through the floor is important mainly for construction that has a crawl space under the building or for buildings that are built up on piers with an open space beneath. For buildings with full basements, this term is usually not important. Therefore, the term involving loss through the floor will not be discussed in this module.

U values express the thermal transmission through an entire structural element, such as a wall. They include all the component elements of the wall. Thus, for a frame wall consisting of wood siding, sheathing, insulation, possible air spaces, studs, and wallboard, the U value represents the heat transmission through the structure consisting of all the components.

Table 1 presents some U values representative of typical types of construction for walls, ceilings (or roofs), and windows. (They are specifically for frame construction and masonry construction.) These values must be considered as approximate because they depend on the exact materials, thicknesses, and so forth. However, they represent typical ranges that may be encountered. Values are presented for varying thicknesses of insulation in the walls and ceiling. From

Table 1, it is obvious that the addition of insulation has a significant effect in lowering heat transmission.

TABLE 1. THERMAL TRANSMISSION COEFFICIENTS — U VALUES ($Btu/ft^2/h/°F$).

WALLS

Insulation Thickness (Inches)	Frame Walls (Wallboard, Studs, Siding)	Masonry Walls (Cinder Block, Brick Facing)
0	0.24	0.16
1	0.13	0.106
2	0.095	0.080
3	0.072	0.064

CEILING/ROOF

Insulation Thickness (Inches)	Frame Construction (Plaster, Plyboard, Shingles)	Flat Masonry (Concrete Slab, Built-Up Roofing)
0	0.60	0.22
2	0.12	0.092
4	0.071	0.059
6	0.050	0.043
8	0.037	0.034

WINDOWS

Window Type	U Value
Single Glass	1.13
Thermopane	0.65
Storm Window	0.56
Triple Glass	0.36

Equation 1 may be used to estimate the total heat loss from a particular building. It may also be used to estimate the major sources of heat loss, with a view toward reducing these losses.

Infiltration is caused from air leakage through cracks, around doors and windows and from flow through walls, floors, and so forth. No building is completely airtight. The exact rate of infiltration depends on the type of construction and the condition of the building. And, because it also depends strongly on the wind velocity at any given time, infiltration is difficult to characterize exactly. Often, infiltration is expressed in terms of air changes per unit time. Thus, if a building has two air changes per hour, the infiltration rate will be enough to replace the air volume completely twice each hour.

Infiltration represents a source of heat loss that may be reduced by weatherstripping, caulking, and other methods. A well-sealed building with good weatherstripping may have an infiltration rate of approximately one-half air change per hour.

It is not desirable to reduce infiltration too much. Adequate air exchange is needed to provide fresh air for the building occupants. Local laws or codes often specify a minimum amount of ventilation for many buildings. A building that is closed up too tightly may not have adequate ventilation. This causes a buildup of odors and air contaminants and leads to problems with excessive condensation of water vapor.

EXAMPLE A: CALCULATION OF HEAT LOSS.

Given: A one story home with the following wall area: 20' x 60' x 8'. There are 20 windows, each 3' x 5'. The home has two inches of insulation in the walls, four inches of insulation in the ceiling and has thermopane windows. Assume that there is enough infiltration so that the inside air is exchanged once per hour. The thermostat is set at 65°F.

Find: The amount of heat loss from the home when the outside air temperature is -5°F.

Solution: The wall area is (20 + 20 + 60 + 60) x 8 = 1,280 square feet (including the windows). The window area is 20 x 3 x 5 = 300 square feet — which leaves 980 square feet for the walls (excluding the windows). From Table 1, the U value is 0.095 Btu/ft^2/h/°F. The temperature difference is 70°F. Thus, the heat loss through the walls is:

0.095 x 980 x 70 = 6,517 Btu/h.

The ceiling/roof area is 20 x 60 = 1,200 square feet. The U value, from Table 1, is 0.071. The heat loss through the roof is:

0.071 x 1,200 x 70 = 5,964 Btu/h.

For the 300 square feet of window area, the U value from Table 1 is 0.65, and the heat loss is:

0.65 x 300 x 70 = 13,650 Btu/h.

Example A. Continued.

The volume of the house is 20 x 60 x 8 = 9,600 cubic feet. This is the volume of air changed by infiltration each hour. Thus, the heat loss due to infiltration is:

0.018 x 9,600 = 173 Btu/h. (rounded from 172.80)

The total heat loss is:

6,517 + 5,964 + 13,650 + 173 = 26,304 Btu/h.

Notice that the largest contribution to the heat loss comes through the windows.

The R value is another factor that is often encountered. The letter R is an abbreviation for resistance. The R value is a measure of the resistance of materials to heat flow. For a particular structure, the R value is related to the U value by the following Equation:

$$R = I/U \qquad \text{Equation 2}$$

Thus, the R value is represented by the units of square feet per hours per degrees Fahrenheit per Btu. In practice, though, the units of R are almost never specified.

From Equation 2, it can be seen that materials with low thermal transmission have high R values. Thus, for insulation, materials with high R values are desirable. The manufacturers of insulation specify the R value of the insulating material. For example, a six-inch thick fiberglass blanket might be specified as "R-18". The R values provide a convenient economic measure. If two types of insulation have the same price per unit area, the one with the higher R value will be the better buy.

A convenient additional feature of R values is that they are additive. Therefore, if insulation is added to a structure, the total R value will be the sum of the R values of the original structure and the added insulation. The R value of a wall may be obtained by simply adding the R values of each component. One precaution is necessary, however. An air space in a structure provides some resistance to heat conduction, and, therefore, has a R value greater than zero. Thus, if one adds insulation into an air space in a wall, one must first subtract the R value of the air space and then add the R value of the new insulation. If one simply adds new blankets of insulation on top of existing insulation in an attic, then the R value of the new insulation may simply be added to the old value.

Table 2 presents some R values for common insulating materials and structural materials. These are approximate values, since they depend on the type of material used. Moreover, the value for the air layer is dependent on exact conditions. Still, these values represent a rough estimate of the thermal resistance for some common materials.

The values in Table 2 are expressed per inch of thickness. Thus, the R value for each material listed in Table 2 must be multiplied by its thickness (in inches) to give the correct R value.

TABLE 2. TABULATION OF R VALUES.

Material	R Value/1" Thickness
Insulating Materials	
Fiberglass batts or blankets	3.1
Mineral wool batts or blankets	3.1
Urethane board	6.0
Polystyrene board	4.5
Urea formaldehyde foam	4.8
Cellulose loose fill	3.6
Mineral wood loose fill	3.1
Fiberglass loose fill	2.2
Vermiculite loose fill	2.1
Structural Materials	
Plywood	1.20
Plasterboard	1.10
Common brick	0.20
Facing brick	0.11
Concrete block (three oval core)	0.18
Plaster (sand aggregate)	0.20
Wood siding	1.30
Vertical air pocket	0.68
Cement mortar	0.20

EXAMPLE B: CALCULATION OF R VALUE AND U VALUE.

Given: From Table 2, the estimates of the R values of the following:

A wall consisting of four inches of facing brick, 0.5 inches of cement mortar, eight inches of concrete block, a one-inch air space, and one inch of plasterboard.

Find: The sum of the constituent R values and the U value.

Example B. Continued.

Solution: First, sum the constituent R values taken from Table 1:

Facing brick	4 x 0.11 = 0.44
Cement mortar	0.5 x 0.20 = 0.10
Concrete block	8 x 0.18 = 1.44
Air space	1 x 0.68 = 0.68
Plasterboard	1 x 1.10 = 1.10
	3.76

The total R value is 3.76; therefore the U value is:

1/3.76 = 0.266.

The first increment of insulation is the most effective in reducing heat loss. Additional increments of insulation progressively have less effect. At some point, it is no longer cost-effective to continue adding more insulation; therefore buying more insulation is unwarranted since it does not produce a proportional reduction in heat loss.

Figure 1 illustrates how heat loss decreases with increasing R value. If one increases the insulation from R-5 to R-10, the heat loss will decrease from 0.2 to 0.1 Btu/h/ft^2/°F. If the R value is increased by five more (to R-15) the added insulation will cost as much. But the heat loss will decrease to 0.067, a smaller change in the heat loss. This example shows that, at a certain point, it is no longer cost-effective to continue adding more insulation. But the question is: Just how much insulation, or how high an R value, should one have?

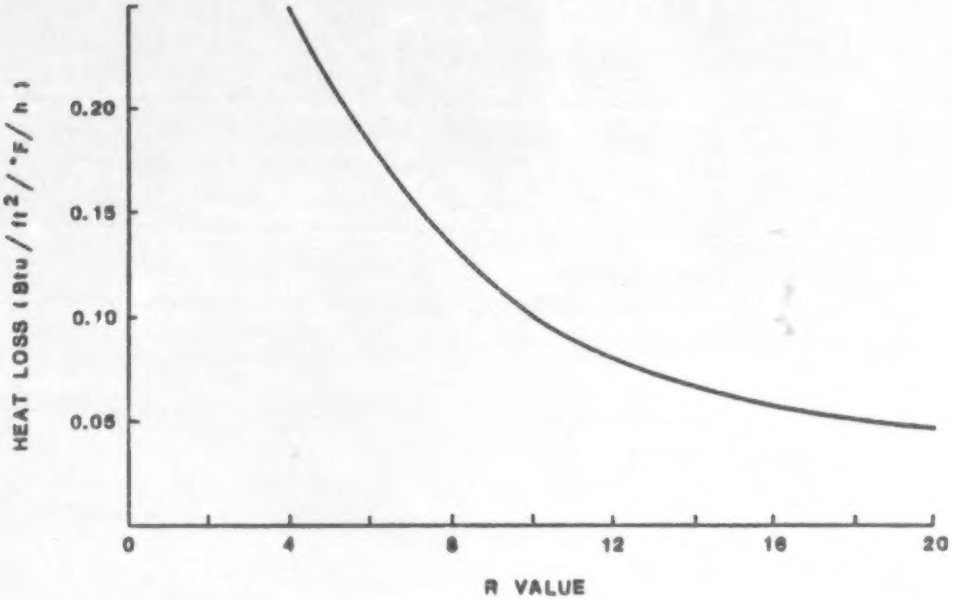


Figure 1. Heat Loss Vs. R Value.

Recommendations for R values for different parts of the United States were formulated in 1977 by the U. S. Department of Energy. Table 3 presents the recommended R values for roofs (or ceilings), exterior walls, and floors (for floors exposed to heat loss). The recommentations are relevant to the six zones of the country that are shown in Figure 2.

TABLE 3. RECOMMENDED R VALUES FOR ROOFS, WALLS, AND FLOORS.

Zone	Roof/Ceiling	Exterior Wall	Floor
1	38	19	22
2	33	19	22
3	30	19	19
4	26	19	13
5	26	13	11
6	19	11	11

One can find the proper zone from the map in Figure 2, and then use Table 3 to determine recommended R values for roofs, walls, and floors for that zone. Adding insulation to attain the recommended R values should produce an efficiently insulated building.

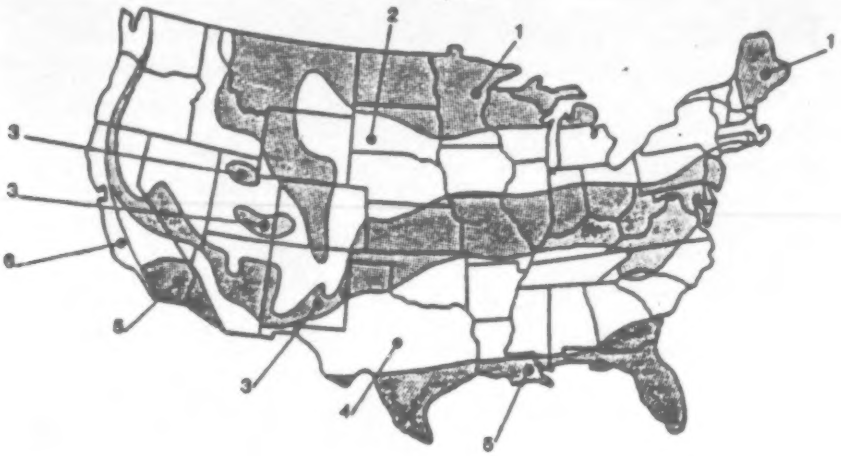


Figure 2. Zones 1-6 in the United States for Which Recommended R Values are Defined in Table 3.

EXAMPLE C: ADDITION OF FIBERGLASS INSULATION.

Given: A home in Maine with a roof that has an R value of seven.

Find: The thickness of a layer of fiberglass batts that should be added.

Example C. Continued.

Solution: Figure 2 shows that Maine is in Zone 1 for the recommendations on insulation. Table 3 will show that the recommended R value for the roof in this zone is 38. Since the existing R value is only seven, it should be increased by 31. Table 2 will show that the fiberglass batts have an R value of 3.1 per inch. Thus, 10 inches of fiberglass batts should be added to increase the insulation of the roof.

EXAMPLE D: ADDITION OF POLYSTYRENE INSULATION.

Given: A building in northern Florida with walls of bare cinder block having a U value of 0.22.

Find: How much thickness of polystyrene board should be added as insulation in order to meet recommended R values.

Solution: From Table 3, the recommended R value is 13 for walls. The R value of the cinder block walls is $1/0.22 = 4.55$. This should be increased by 8.45 to bring the R value up to 13. From Table 2, polystyrene board has an R value of 4.5 per inch of thickness. Two inches of polystyrene board will increase the R value by 9, bringing it up to 13.55, above the recommended value.

The main source of heat gain - and an increased heating load - in the summer is solar radiation entering the building through windows. Heat gain by conduction is relatively less.

Only rarely - if ever - would it be cost-effective to add insulation to the walls or ceiling just for the purpose of reducing heat gain in the summer. But insulation added to reduce heat loss in the winter will be somewhat beneficial in reducing heat gain in the summer.

Solar radiation accounts for most of the heat gain in areas having high levels of solar radiation. The geographical distribution of total daily solar energy in the United States in the summer has already been discussed in Module EP-03, "Generation of Steam, Hot Water, and Hot Air, Using Solar Collectors." The student may refer to Figure 5 of that module for a review. The total solar radiation is greatest in the southwestern United States, and it is less along the northeastern coast.

For a particular geographical location, the heat gain depends on the direction that the window is facing. The heat gain is greatest when windows face east and west, next to the greatest when windows face south, and least when windows face north. The gain for south-facing windows is not the best in summer because the sun is high above the horizon at noon, and a south-facing window is illuminated at an oblique angle. An east- or west-facing window will receive the sunlight straight-on in the morning or afternoon, and, thus, will provide more heat gain. The situation is different in winter when the sun is lower. Then, a south-facing window will receive the sun's rays nearly straight-on near noon and will provide the greatest heat gain.

An idea of the magnitude of potential heat gain is given in Table 4, which gives the amount of solar radiation for several values of latitude that strikes one square foot of window area on June 21. For comparison, a city near each value of latitude is listed. The values presented are the number of Btus that will reach each square foot of window area on a clear day, with no shading. Thus, a west-facing window in Philadelphia, Pennsylvania, with an area of 3' x 5' will receive 15 x 1,226 = 1,839 Btu of solar energy on June 21. This, of course, represents a very large potential heat gain.

Not all of this amount will actually be converted into heat inside the building. The exact amount depends on the type of window, the absorption of the window glass, possible shading, possible cloudiness, and the temperature difference between the inside and outside. Thus, the exact solar heat gain through a specific window depends on many factors, and calculation of the solar heat gain becomes complicated. Still, the numbers in Table 4 indicate that, potentially, solar heat gain through windows can be a very large source of added heat load in the summer.

TABLE 4. POTENTIAL SOLAR RADIATION ON JUNE 21.
(Btu/ft^2/d)

Latitude	City Near That Latitude	Direction Window Faces			
		North	East	South	West
32°N	Savannah, GA	532	1169	450	1169
40°N	Philadelphia, PA	506	1226	630	1227
48°N	Minot, ND	514	1284	872	1284

The discussion will now describe an energy survey for buildings; then it will move to a discussion of energy conservation practices relevant to building design and use, both for new buildings and existing buildings.

ENERGY SURVEY FOR BUILDING CONSTRUCTION

An audit of the building materials and construction can be an important first step for energy conservation in building use. A suggested energy survey for building structures and materials is given below. This survey can highlight some of the possible ways to save energy in a specific building. Later, the student will prepare an energy survey for building structure and materials in a specific building.

TABLE 5. ENERGY SURVEY – BUILDING STRUCTURE AND MATERIALS.

Ceiling/Roof

Area of ceiling or roof: _______ square feet
Structural materials: _______
____
Insulation: Type _______
Thickness _______

Exterior Walls

Area of walls: _______
Structural materials: _______
____
Insulation: Type _______
Thickness _______

Floor

Area of floor: _______ square feet
Structural materials: _______
____
Insulation: Type _______
Thickness _______
Exposure of floor (full basement, crawl space pier construction, etc.): _______

Table 5. Continued.

Windows

Number of windows: ________
Exposure (How many face north, east, south, west): ________
Area of windows: ________ square feet
Type of windows (single glazing, thermopane, etc.): ________
Weatherstripping and caulking present?: ________
Condition of weatherstripping and caulking?: ________

Heating and Cooling Plant

Size of furnace: ________ Btu/hour
Fuel used: ________
Size of air conditioning system: ________ Btu/hour (or tons)

Special Features

Vestibules, enclosed entryways, shade trees, awnings, solar collectors, etc.: ________

DESIGN CONSIDERATIONS FOR REDUCTION OF ENERGY LOSS FOR NEW BUILDINGS

The potential for energy savings is greatest when a new building is being constructed. In an existing building, many factors, such as siting, materials of construction, and so forth, have already been chosen, and they are not subject to change. But during the design of a new building, all the choices are available. New buildings can be designed for energy conservation with little or no increase in the cost of construction.

Some of the design considerations that may be incorporated into new construction are discussed on the following pages.

CHOICE OF SITE AND ORIENTATION OF BUILDING

The choice of the site and orientation of a building can be effective in reducing energy loss. In some cases, the location can be chosen to be sheltered from wind in the winter. The wind-sheltering can be provided by contours in the land or by trees.

The building can also be oriented to receive the maximum of solar energy that is available in that location in winter. Large walls with many windows should face toward the south, so as to take advantage of this source of energy.

CHOICE OF MATERIALS

Table 2 shows that thermal transmission of different structural materials varies. The building designer should choose materials that minimize heat loss from the building. The choice must be consistent with other requirements, such as the relative cost of the different materials.

ADEQUATE INSULATION

The building design should include adequate insulation to provide the R values recommended by the Department of Energy. These values were defined in Table 3 for ceilings, walls, and floors in several areas of the United States.

INCLUSION OF A VAPOR BARRIER

When a building becomes tightly sealed to reduce infiltration of air, a problem may arise with condensation of moisture. Water vapor will condense on cold surfaces. Condensation in a well-sealed and insulated building can cause moisture damage to building components, such as studs, wallboard, joists, and so forth. It can also wet the insulation and reduce its effectiveness for thermal resistance.

Installation of vapor barriers can prevent this problem. Vapor barriers should be included on the warm side of the insulation. Vapor barriers are often plastic sheets that are stapled to the inside of the wall studs next to the insulation. Vapor barriers are most important in cold climates and in conditions where there is a large amount of moisture release in the building.

VENTILATION

Adequate ventilation must be included in the building design. Lack of ventilation can lead to moisture condensation, with the same problems as discussed above. Inadequate ventilation will also result in a buildup of odors and air contaminants. The amount of ventilation required for commercial and industrial buildings is often prescribed by local laws and codes. For homes, a rough value of one square foot of vent area for each 150-300 square feet of attic area is recommended.

EARTH-SHELTERED DESIGN

A type of building design that is gradually being introduced in the northern United States is the earth-sheltered design. This type of construction generally involves banking earth around the northern, eastern, and western edges of the building – and perhaps over the top. The southern exposure is left open with several windows that collect energy. An alternate method is to embed the building in the side of a south-facing hill or cliff.

Earth-sheltered design is a radical departure from conventional design. It does offer great savings in heating and cooling energy. For example, one 2,800 square foot earth-sheltered home in Minnesota is estimated to have an annual heating cost of $47, far below the cost for conventionally designed homes in that area.

The design of such buildings can be acceptable to the building's occupants and can avoid a feeling of being buried underground. Earth-sheltered design is applicable for many building types, including homes, industrial plants, office buildings, and so forth. This design is perhaps best adapted to one- and two-story buildings, and is probably limited in its applicability for high-rise buildings.

CHOICE OF WINDOWS

In many cases, windows are considered a desirable part of architectural design. Most buildings are designed to include windows, although some are not. Windows contribute to heat exchange between the building and the outside. Glass is a poor insulator; therefore heat penetrates through windows more easily than it does through the surrounding wall. Sometimes it is recommended that the area of a building devoted to windows be reduced in size. In fact, some sources recommend that a building have no more than 10% of its wall area to include windows.

Windows can be desirable for admitting daylight and for boosting occupant morale. At the same time, south-facing windows receive sunlight during the winter and reduce the heating load. In summary, window design can provide reduced heat loss, allow entrance of sunlight, and offer many other desirable features.

Windows that reduce heat loss in the winter should be used in new buildings. The U values for various types of window construction are given in Table 1. A single thickness of glass generally is undesirable because of the high degree of heat loss incurred. Adding a second sealed layer of glass (or a storm window) traps a layer of air and greatly reduces heat transmission. The design of new buildings should include at least two layers of glass with an air space between. Triple glazing is recommended for colder climates where there are more than 6000 heating degree-days. This design involves three layers of glass with sealed air spaces between them. The building design should provide for as many windows as possible to receive sunlight in the winter.

The so-called "greenhouse effect" is worth mentioning. Short wavelength radiation is readily transmitted through glass. Thus, the visible and near infrared portion of the solar spectrum, which contains most of the solar energy, will penetrate the window and enter the building. Glass does not transmit the longer wavelength infrared radiation that is characteristic of the thermal radiation from objects near room temperature. Because of the greenhouse effect, sunlight is very effective in warming spaces enclosed by glass.

However, excessive heat gain from sunlight in the summer may be a problem under some conditions. There are a number of types of tinted, heat-absorbing glass, or coated reflective-type glass that can reduce heat gain in the summer. Use of such glasses can reduce the cooling load as much as 30%. The choice of such heat-rejecting glass should be considered for use in windows under conditions where reduction of summer heat gain is desired.

PROPER SIZING OF HEATING SYSTEM

In the past, it was common practice to install larger heating systems than was necessary. Then, energy was relatively inexpensive. Oversized heating systems are now considered inefficient because they waste energy. They cycle on and off, and spend a large fraction of the time reheating the plenum. A smaller furnace that operates for longer periods at a time can provide a larger fraction of its heat as useful input to the building. An earlier module, Module EC-02, described these considerations.

A properly sized heating system should operate continuously on a day that is deemed the coldest in the climate where the building is located. The heating system should be just large enough to maintain a constant indoor temperature (while operating continuously) during the coldest weather that occurs at that location.

From weather records, the building designer should determine the coldest weather to be expected and estimate the building heat loss during that time. The furnace chosen should be one that will just balance that particular heat loss.

A variation of the above technique involves the use of a modular heating system. This method incorporates the use of several furnaces of different sizes. The total capacity of all the furnaces is adequate for the coldest weather. During warmer periods (such as autumn and spring) some of the modules (furnaces) will not be used. The goal is to have the heating system, whatever fraction is being used, operate at a high duty cycle at all times.

A single large furnace might operate almost continuously in winter, but it would frequently cycle on and off in warmer weather. Use of a modular system avoids this situation since some of the heating modules would shut off when the weather warmed up. The remaining operating modules could then operate more efficiently.

RECOVERY OF WASTE HEAT

Heat that is usually wasted can be recovered in part and used to substitute for part of the heating load. One example is the heat contained in the flue gases that escape up the smokestack. Although flue gases cannot be allowed to enter the building because they contain combustion products and, possibly, carbon monoxide, they can be passed through heat exchangers and part of their heat energy reclaimed.

Other places where waste heat can be recovered include the hot gases from refrigerating system exhausts, hot water drains, engine exhausts, and lighting fixtures.

Design of an energy efficient building should include the recovery of waste heat energy from as many sources as possible.

FLUE DAMPERS

The furnace flue must be open when the furnace is on in order to allow combustion products to escape. But when the furnace is off, heated air may escape up the flue. This represents a loss of the energy that was previously used to heat the air.

This type loss can be avoided by the installation of a flue damper, which is left open when the furnace is on and closed when the furnace is off. Commercial flue dampers that are motorized and automated are available.

The potential danger of using flue dampers (as stated previously) could occur if they were to remain closed during the time that the furnace is on. In this case, combustion products, including carbon monoxide, could enter the building. Thus, flue dampers must be designed to be fail-safe. Because of the potential danger, the construction and installation of a flue damper is not recommended for an amateur installer. Rather, proven equipment should be installed by trained personnel.

AUTOMATED CONTROL OF HEATING AND COOLING

Centralized automated control of heating and cooling functions has been described in Module EC-02. Such automated functions, under the control of a computer, can provide considerable savings in energy. The installation of automated computerized controls in large buildings is strongly recommended.

In smaller buildings or in private homes the cost of a computerized system may not be justified. In this case, use of fuel saver thermostats can provide some degree of automated control. The thermostats can be programmed to turn down the heat automatically when the building is empty or when occupants are sleeping. Some models of fuel saving thermostats can be programmed for multiple setback/startup cycles during the day, and at the same time can be programmed for different cycles on different days of the week. The use of fuel saving thermostats with multiple setpoints can lead to savings of 15-25% of heating energy, depending on the climate.

COLOR OF ROOF

A dark roof absorbs heat energy, whereas a light roof will reflect it. Thus, a light roof is desirable in situations where the cooling load in summer is greater than the heating load in winter. In cases where the winter heating load is greater, and where there is considerable sunshine in the winter, a dark roof will absorb solar energy and will help reduce heating requirements.

THERMAL STORAGE

Thermal storage systems are becoming more popular. These systems involve large, well-insulated storage volumes. The material in the volume – sometimes rocks or bricks – heats, then stores, the thermal energy. The energy is then extracted and used to heat the building at a later date. Thermal storage systems can also be used for cooling. The energy is transferred between the storage volume and the building by a fluid, usually either water or air. A thermal storage system can aid in the following applications:

- Leveling of load in electric space heating or cooling
- Conservation of waste heat
- Resizing of heating equipment
- Avoidance of peak load in hot water heating
- Utilization of solar energy

In some cases, very large thermal storage systems can operate over a six-month cycle, storing heat in the summer, thereby cooling the building, and releasing it in the winter for heating. The energy conservation opportunities offered by thermal storage should be considered during the design of a new building.

UTILIZATION OF SOLAR ENERGY

Solar energy and its potential for reducing energy consumption should be evaluated for any new building. Solar energy can be used for the following:

- Hot water heating
- Space heating
- Cooling with absorption cooling systems
- Photovoltaic electric generation

The technology and applications for generation of steam, hot water, and hot air, using solar collectors have been described in detail in Module EP-03. The photovoltaic generation of electricity with solar energy was presented in Module EP-07.

HEAT PUMPS

Essentially, heat pumps are air conditioners that work in reverse. They are electrically operated, and they extract heat from the outside air and deliver it inside. Heat pumps can operate with an efficiency greater than 100%. In other words, a heat pump can deliver more than one Btu of heat energy for each Btu of electrical energy used. This is true because the heat pump does not generate the energy itself, but extracts it from the air. This fact makes heat pumps highly desirable.

Heat pumps operate at highest efficiency when the outside air temperature is not too low – perhaps above 20°F. At very low temperatures – perhaps below -10°F – they become ineffective. These factors tend to restrict the widespread use of heat pumps in the northern United States. However, they can be used effectively in milder climates, or as supplemental heating sources in cold climates.

REDUCTION OF ENERGY LOSS - RETROFIT IN EXISTING BUILDINGS

There are fewer energy saving possibilities in an existing building than in one that is being constructed. Several important options are not available, such as choice of site and choice of construction materials. Other energy-saving measures involve replacement of existing components - which may be more difficult to justify economically. Nevertheless, there are effective energy saving measures that can be adapted to retrofit an existing building, some of which are described in the following paragraphs.

CAULKING AND WEATHERSTRIPPING

Heat loss occurs by infiltration of cold air through cracks and other spaces, especially around doors and windows. Sealing these openings by caulking and weatherstripping is an important method for reducing heat loss by infiltration. If the building does not have caulking or weatherstripping , they should be applied and installed. If the caulking is old, it should be reapplied. If the weatherstripping is cracked or otherwise damaged, it should be replaced. Specific techniques for applying caulking and installing stripping are described in the section entitled "Infiltration."

ADDING STORM DOORS

Storm doors help reduce heat loss due to infiltration. The addition of storm doors to buildings that do not have them is highly desirable in cold climates.

ADDING A VESTIBULE

A vestibule can reduce the influx of cold air when the door is opened. A vestibule is more costly to add than storm doors, but it can be an effective method for reducing heat loss in cold, windy climates.

ADDING A WINDBREAK

Adding a windbreak outside the building can also reduce the amount of cold air that enters a building when the door is open. Windbreaks are particularly effective when there are prevailing winds which tend to blow in a certain direction during the winter, such as in parts of the northern United States. If the prevailing winds blow toward the door, a large amount of cold air can enter when the door is opened.

Windbreaks can reduce this rush of cold air. Windbreaks can be produced by trees, by bushes, or by fences. Evergreen trees or bushes are more effective than plants that lose their leaves in winter.

ADDING STORM WINDOWS OR ADDITIONAL GLAZING

Adding storm windows to buildings that do not have them is an effective means of reducing heat loss. Even if storm windows are present, adding an additional sheet of glass, separated from the existing glass by a sealed air space, may be desirable in cold climates. More specific recommendations about reducing heat loss through windows are discussed later in the module.

ADDING INSULATION

Adding insulation to bring the R values up to the recommendations of the Department of Energy is desirable. If the building has no insulation, it should be added to the ceiling and walls. If insulation is present, but with lower R values than recommended, additional insulation should be added when it is feasible. Specific methods for adding insulation are described later in the module.

ADDING AUTOMATIC CONTROLS

Automatic computerized central controls for large buildings and fuel-saving thermostats for smaller buildings were discussed in previous sections. These may also be added to existing buildings. The cost effectiveness might be reduced because they would replace existing installed components; but, in most cases, they would still be economically justified.

ADDING AWNINGS AND OTHER SHADING DEVICES

Awnings and other shading devices reduce solar heat gain and its added heat load. Awnings are effective because they block the sunlight from entering the window when the sun is high in the sky in the summer. When the sun is low in the sky in the winter, sunlight enters the window below the awning.

Other shading devices include drapes, shades, and venetian blinds that are hung inside the window. Shade trees are also desirable, but they require several years to grow tall enough to be effective.

ADDING FLUE DAMPERS

Flue dampers, which were described earlier, may be added to existing buildings. Their cost effectiveness are as high in an existing building as in a new one because they do not replace existing components.

RESIZING THE HEATING SYSTEM

As discussed previously, an oversized heating system is a source of energy loss. Many buildings have heating systems that are larger than is necessary because they were incorrectly sized. Even if the heating system is the correct size for the building, the implementation of energy-saving measures such as storm windows, additional insulation, and so forth, may make the heating system oversized. The capacity of a furnace may be changed somewhat without having to replace the entire furnace. For instance, the orifices through which the fuel enters the burner can be reduced in size. This has the effect of reducing the furnace capacity. Such resizing of the furnace should be left to trained personnel, however.

A procedure for determining whether a heating system is properly sized was described in Module EC-02.

MAINTAINING HEATING SYSTEMS

Annual checkup and maintenance of the heating system should be performed by qualified personnel. This can reduce heating expenses. The maintenance and testing should include the following:

- Adjusting and cleaning burner
- Adjusting fuel-to-air mixture (see Module EC-02)
- Cleaning heating elements and surfaces
- Adjusting dampers
- Changing oil burner nozzles
- Measuring stack temperature (see Module EC-02)
- Measuring stack gas composition (see Module EC-02)

ADDING SOLAR ENERGY EQUIPMENT

Solar panels may be added to existing buildings for hot water heating, space heating, or space cooling. See Module EP-03 for a discussion of solar energy technology.

SPECIFIC TECHNIQUES FOR ENERGY CONSERVATION IN EXISTING BUILDINGS

This section discribes in more detail specific techniques for the conservation of energy by retrofiting existing buildings. The discussion emphasizes control of heat loss from existing buildings and describes methods for control of the following:

- Window loss
- Heat loss through walls and ceilings
- Infiltration

These methods are emphasized because they can generally be carried out by personnel not having specialized training. Some of the methods discussed earlier (such as installation of flue dampers) should be performed only by personnel trained for working with this particular type of equipment.

WINDOW LOSS

Table 1 clearly shows that heat loss through windows can be reduced by the installation of additional glazing, separated from the existing glass by a sealed air space. Single glazing is acceptable for winter use in only a few warm sections of the United States. Addition of storm windows is recommended if the windows are single glazed. In cold climates, triple glazing may be desirable.

There are several ways that additional glazing can be added:

- Combination storm windows
- Single-pane storm windows
- Plastic Sheets
- Draperies, blinds, and shades

Combination Storm Windows

Combination storm windows normally are installed by a contractor, and they are the most expensive of the alternatives listed above. Combination storm windows are available in designs which may be installed over conventional double-hung or sliding windows. They are permanantly installed, and they can be opened for ventilation. They may be used to increase single glazing to either double or triple glazing.

Single-Pane Storm Windows

Single-pane storm windows are less expensive, but they have the disadvantage of being difficult to open. The panes may be glass or rigid plastic, with plastic being less expensive. They can be purchased in frames built to the user's specifications and dimensions. The storm windows may be mounted by the user on the inside of the existing windows and held in place with screws or clips.

Plastic Sheets

Plastic sheets are the least expensive of the alternatives, and the easiest to install. Polyethylene sheets (about 0.0006" thick) are available in sheets or rolls. The sheet may be attached to the inside of the window and may cover the entire casing. It is attached with masking tape. The plastic sheets are effective in trapping a layer of insulating air on the inside of the window. The main disadvantage of plastic sheets is their appearance, which is not as pleasing as that of glass or rigid plastic.

Draperies, Blinds, and Shades

Heat loss in winter can be reduced by draperies, blinds, or shades that cover the window when the sun is not shining. These work best if they trap a layer of air. They should be closed at the top, and fit closely to the frame of the window. Similarly, drapes, blinds, or shades will reduce heat gain through the windows in the summer when the sun is shining on the windows.

HEAT LOSS THROUGH WALLS AND CEILINGS

Control of heat loss through walls and ceilings is accomplished by insulation. Insulation should be added to bring the R value for the wall or ceiling up to the value recommended for the section of the country in which one lives. (See Figure 2 and Table 3.) First, the R value of the existing structure must be determined. (The reference section of this module lists books that contain detailed tabulations for many different types of construction.) Then, add insulation to bring the R value up to the recommended level. The R values per inch of thickness for common types of insulation are presented in Table 2. Common forms of insulation are listed in Table 5, along with typical uses for each type.

Insulating with Batts or Blankets

Batts or blankets may be laid on the floor of an unfinished attic, or laid on top of existing insulation. They may

TABLE 6. TYPES OF INSULATION.

Type	Materials	Where Used
Batts or Blankets	Fiberglass, rock wool	Unfinished attic floor or rafters; underside of floors
Rigid Board	Polystyrene, urethane, fiberglass	Basement walls
Loose Fill	Fiberglass, rock wool, cellulose, vermiculite	Attic floors, (finished or unfinished), finished walls
Foam	Urea formaldehyde	Finished walls

be stapled into place on the rafters of an attic or the underside of a floor. Batts and blankets are easy to install, and they may be installed by personnel with relatively little training.

Some batts and blankets have a vapor barrier on one side. Batts or blankets should be installed with the vapor barrier on the inside, toward the heat. If batts or blankets are added on top of existing insulation, the new insulation should not have a vapor barrier. If there is no vapor barrier on the batts or blankets, and one is needed, plastic sheets can be laid under the insulation in the attic, or can be stapled to the inside of wall studs with the insulation between the studs. The amount of thickness that will increase the R value to the desired value should be used.

Insulating with Rigid Board

Rigid board may be used for applications such as insulating basement walls. For relatively small thicknesses, extruded polystyrene and urethane have a high insulating value. They form their own vapor barriers and do not need additional vapor barriers. These types of rigid board are available in widths of two to four feet and in thicknesses up to four inches. It is important to note that polystyrene and urethane rigid board should only be installed by a contractor. And, they must be covered with one-half inch thick gypsum wallboard as a precaution against fires. These factors somewhat restrict the use of the rigid board types of insulation.

Insulating with Loose Fill

Loose fill can be used for insulating attic floors or for finished walls. Cellulose-based loose fill must be treated with fire retardants. For an unfinished attic, loose fill may be poured in between the joists. It is poured to a depth sufficient to give the desired R value. This type of installation is relatively easy and may be performed by personnel with little training.

For finished attics or finished walls with no insulation, loose fill may be blown in. This is a more difficult job and normally is done by a contractor. Holes must first be cut in the walls; then the insulation is blown in by pressurized air through a flexible hose. When the spaces are filled, the holes are resealed and refinished.

Insulating with Foam

Foam insulation is pumped through flexible hoses into holes in finished walls to fill up the empty space inside. Foam insulation has a higher R value per unit thickness than loose fill has. It is also more expensive than loose fill. The installation of foam insulation is difficult and should be done by a contractor. Even then, sometimes the quality of the installation is inconsistent – which makes it important to select a qualified contractor who will guarantee the result.

Adding More Insulation

Walls that have never been insulated can be treated with loose fill or foam. But what about walls that are already filled with insulation but need more? In this case, loose fill or foam cannot be blown or pumped into the wall. This type of project requires the addition of a separate layer to the inside of the wall. Adding insulation involves installing 2" x 4" studs along the inside of the walls and adding insulation between the studs. Fiberglass batts or blankets may be stapled to the studs, for example. Then, wallboard or paneling is added to finish the wall. This approach is relatively expensive and requires the skills of a carpenter.

INFILTRATION

Infiltration of cold air into the building may be reduced by the following methods:

- Caulking
- Weatherstripping
- Installing storm doors

Caulking

Caulking is important and should be applied to windows and and doors. Previously applied caulking should be inspected periodically to make sure tha cracks are completely filled. If the caulking is old, cracked, or pieces are missing in places, then new caulking should be applied.

Caulking comes in various forms. Oil-based caulking is the least expensive and is also the least durable. Latex-based caulking is more expensive but more durable. Other types of caulking are available – for example, elastomeric compounds such as silicones. These are the most expensive and the most durable. Caulking in the form of oakum or cotton caulk is used to fill wide cracks.

Caulking should be used wherever two different materials meet. Examples are: around frames of windows or doors, at corners in the building, at the junction between the foundation and the main part of the building, and at any breaks in the outside surface.

Caulking comes in tubes, and is applied with a caulking gun. Both are readily available and may be applied by persons with little training. However, some practice may be needed in order to draw a good bead of caulk that adequately fills the crack. Caulking should only be applied when the outdoor temperature is above some minimum temperature (often 40°F), but this depends upon the material.

Weatherstripping

Weatherstripping is used to seal the edges of windows and doors. It should be unbroken and form a complete seal. Weatherstripping should be replaced if it is damaged or missing in places, or it should be added if there is no weatherstripping present.

Weatherstripping comes in a variety of forms, such as metal-backed felt, rolled vinyl with metal backing, unbacked rolled vinyl, spring metal, and foam rubber with adhesive backing. The choice depends on the particular construction of the door or window that is to be sealed. Weatherstripping may be installed by persons with a minimum of carpentry skills, as long as instructions that appear on the packaging are followed.

Installing Storm Doors

Storm doors are designed to be installed outside the regular outside door. There are many types available, and they can be designed to fit a specific door. In order to assure proper fit, the installer should possess adequate carpentry skills. Storm doors are often installed by a contractor who supplies doors with the proper dimensions.

ADVANCED TECHNIQUES TO MEASURE ENERGY LOSS FROM BUILDINGS

The determination of energy loss from buildings is a mature technology which tends to use long-established, unsophisticated methods. The usual approach is to determine the R value of the materials used in the building construction, and then to use the equation presented in this module as Equation 1. This method often underestimates heat losses because there may be localized areas of high loss that are not accounted for in the estimate of the R value.

The determination of infiltration loss is not exact. It is often qualitative, depending on visual examination of caulking, weatherstripping, and so forth. Methods of determining infiltration loss quantitatively have not yet been accepted.

In repsonse to the needs for more sophisticated diagnostic techniques, some advance methods for determining energy loss are being developed, including the following:

- Infrared scanning
- Blower doors

INFRARED SCANNING DEVICES

Infrared scanning systems (also called thermal imaging systems) rely on the fact that warm materials emit infrared radiation. The warmer the material is, the more infrared radiation is emitted. An infrared scanning system uses infrared detectors to produce a picture (image) of the infrared radiation produced by the building. The picture will be bright in places where the building is warm. These bright spots will identify places where heat is escaping. This technique offers a powerful method for locating specific heat leaks that are difficult to find by conventional methods. A number of contractors – many of whom tend to be small independent companies – offer infrared scanning for a reasonable fee.

BLOWER DOORS

Another diagnostic technique is the blower door – which consists of a powerful fan mounted and sealed in a door frame. This increases the pressure inside the building. The blower door is often used in conjunction with infrared scanning devices, since they help to identify places where warm air is escaping from the building.

These two approaches to measuring energy loss from buildings have become popular as a result of the response to increased energy prices. Further advances in technology that is designed to monitor energy efficiency is expected in the near future.

EXERCISES

1. Define the terms "U" and "R" as they relate to thermal transmission.
2. A wall has an R value of 25 and an area of 600 square feet. What is the U value for the wall? If the inside temperature is 65°F and the outside temperature is 5°F, what is the heat flow through the wall, in Btu/h?
3. List at least 10 design considerations that can be implemented to reduce energy loss in new buildings.
4. List at least 10 methods for energy conservation in existing buildings by retrofit.
5. List two advanced techniques that can be used to determine energy loss from buildings.
6. Describe the following methods for conserving energy in existing buildings:
   a. Methods for control of window loss
   b. Methods for control of heat loss through walls and ceilings
   c. Methods for control of infiltration
7. What should the R value of the ceiling insulation be in Albany, New York, and in Dallas, Texas, according to the Department of Energy's recommendations?
8. Estimate the heat loss from a particular residence. Using Equation 1, assume a typical winter temperature in the surrounding area. Use the values for areas of walls, windows, and so forth that is taken from the energy survey. Use Table 1 to estimate approximate U values for the type of construction in the selected residence. Estimate infiltration by assuming 0.5 air changes per hour in tight, new construction that has good caulking, weatherstripping, and so on; one air

change per hour in average construction; and two or more air changes per hour in older construction that has loose fitting windows and doors, cracked or damaged caulking and weatherstripping, and so on. What contributes the largest component of heat loss? What can be done to reduce this heat loss?

LABORATORY PROCEDURES

The student will first prepare an energy survey for a specific building. In contrast to the energy surveys performed in earlier modules of this course, it is suggested that the energy survey be conducted on the student's own residence. This will give the student specific ideas about reducing the energy consumption of that residence.

Perform the energy survey by using the form located in the Date Table. Fill in the form as completely as possible. Then evaluate the answers to locate potential methods for the reduction of energy usage in this residence.

In order to determine insulation thickness, it may be necessary to open a space into a wall or ceiling. A cover may be removed from a light switch in a wall or a cover plate from a light fixture in a ceiling; then a flashlight may be used to look into the space.

Next, the student will measure the R value of insulation by using a piece of test apparatus. The test apparatus can be constructed by the class as a whole or as an advanced student project. Construction of individual test apparatuses for each student would be too time-consuming.

The test apparatus consists of a heater, a guard ring to eliminate heat losses, and water-cooled metal plates. Two sheets of the sample to be measured are placed between the heater and the water-cooled plates. A side view of the apparatus is shown in Figure 3:

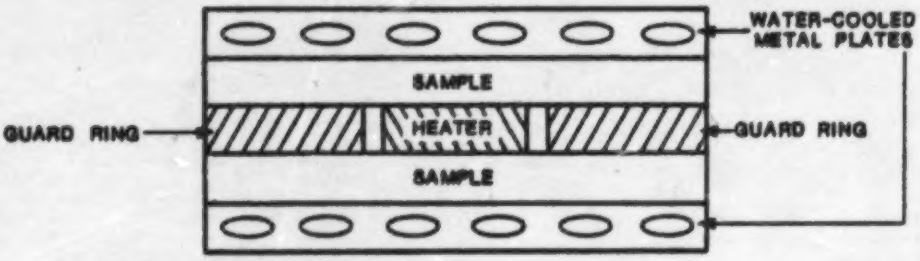

WATER-COOLED METAL PLATES
SAMPLE
GUARD RING
HEATER
GUARD RING
SAMPLE

Figure 3. Side View of Test Apparatus.

The heater itself may be either circular or square. It has an asbestos board with electrical resistance wire wound around it. Aluminum plates (about one-eighth inch thick) are placed on the edge of the heater, with electrical insulation between the wires and the plates. A side view of the heater is shown in Figure 4.

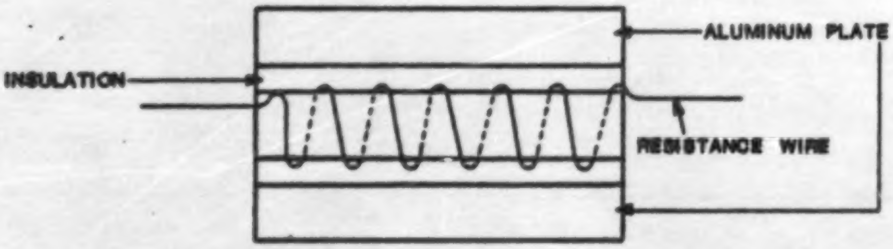

ALUMINUM PLATE
INSULATION
RESISTANCE WIRE

Figure 4. Side View of Heater.

The guard ring is constructed in the same manner as the heater: asbestos board with resistance wire wound on it, insulation, and outer aluminum plates. The guard ring surrounds the heater on all sides and minimizes heat loss to the side. The metal plates of the heater and those of the guard ring are separated by a small gap containing insulation.

Both the heater and guard ring are electrically heated by current passing through the resistance wire. The temperatures of both the heater and guard ring are monitored with thermocouples. (The student might want to review a physics text that explains the use of thermocouples as temperature measuring devices.) Adjust the current through the heater and guard ring so that the temperatures of the heater and guard ring are equal. After each adjustment, wait some time for the temperature to stabilize.

The outer metal plates should have channels drilled in them for water flow through them. Water connections are attached to the end of the channels. During use, the plates are cooled by flowing water.

(Note: The apparatus described above should be constructed and available ahead of time.)

For the measurements of R value, obtain several (three or four) types of commercial insulation. There should be two pieces of each type, each large enough to cover the combined area of the heater and guard plate (see Figure 3). Attach fine-wire thermocouples to the inside and outside edges of the sample. If possible, the thermocouples should be attached to the paper or vapor barrier material which forms the side of the sample.

Then, assemble the apparatus with one of the sample materials between the heater and water-cooled plates, as shown in Figure 3. Turn on the electric current in the heater and guard ring, and turn on the water flow in the outer plates. Adjust the currents to obtain equal temperatures in the heater and guard ring.

When the temperatures have stabilized, measure the following quantities:

a. I = heater current (amperes)
b. V = heater voltage (volts)
c. t_i = temperature of inner side of sample (°F) from thermocouple reading on sample
d. t_o = temperature of outer side of sample (°F) from thermocouple reading on sample
e. A = area of heater (square feet)

Then, determine the thermal transmittance U ($Btu/h/ft^2/°F$) from the following equation:

$$U = 3.412\ IV/A\ (t_i - t_0)$$

Then use Equation 2 to find the R value. Compare this value to the value quoted by the manufacturer.

Repeat the measurements and calculations for the other samples of insulating material.

DATA TABLE

DATA TABLE. ENERGY SURVEY – BUILDING STRUCTURE AND MATERIALS.

Ceiling/Roof

Area of ceiling or roof: ________ square feet
Structural materials: ________
____
Insulation: Type ________
Thickness ________

Exterior Walls

Area of walls: ________ square feet
Structural materials: ________
____
Insulation: Type ________
Thickness ________

Floor

Area of floor: ________
Structural materials: ________
____
Insulation: Type ________
Thickness ________
Exposure of floor (full basement, crawl space pier construction, etc.): ________

Windows

Number of windows: ________
Exposure (How many face north, east, south, west): ________
Area of windows: ________ square feet
Type of windows (single glazing, thermopane, etc.): ________
Weatherstripping and caulking present?: ________
Condition of weatherstripping and caulking?: ________

Data Table. Continued.

Heating and Cooling Plant

Size of furnace: ________ Btu/hour
Fuel used: ________
Size of air conditioning system: ________ Btu/hour (or tons)

Special Features

Vestibules, enclosed entryways, shade trees, awnings, solar collectors, etc.: ________

REFERENCES

ASHRAE Handbook and Product Directory, 1977 Fundamentals. Chapters 21, 22, and 26. New York: American Society of Heating, Refrigerating and Air Conditioning Engineers, 1977.

Wilkes, Gordon B. Heat Insulation. Chaper 9 and Appendix 4. New York: John Wiley & Sons, Inc., 1950.

In the Bank ... or Up the Chimney. Stock Number 023-000-00411-9, Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (1977).

TEST

1. The U values that express thermal transmission through a material have units of ···
   a. Btu/h
   b. Btu/ft^2
   c. $Btu/ft^2/h/°F$
   d. $Btu/ft^2/°F$
2. The R value that expresses resistance to heat flow is defined as ______________________________.
3. For insulation that has an R value of 20, the U value is ···
   a. 0.005
   b. 0.05
   c. 0.5
   d. 5.0
4. A wall with an area of 1000 square feet has an R value of 20. The outside temperature is 50°F below the inside temperature. What is the heat flow through the wall, in Btu/h?
   a. 250
   b. 2500
   c. 400
   d. 1,000,000
5. Design considerations to reduce energy loss in new buildings includes inclusion of a __________ barrier, __________ sheltered design, proper __________ of the heating system, recovery of __________ heat, __________ storage, and utilization of __________ energy.
6. Methods for energy conservation in existing buildings by retrofit include caulking and __________, adding __________ and shading devices, __________ the heating system, and __________ maintenance.

7. According to the Department of Energy's recommendations, the insulation in the walls of a home in Little Rock, Arkansas, should have an R value of ...

a. 22

b. 19

c. 13

d. 11